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R L ALUMBAUGH ET AL. JAN 83 CEL-TN-1656

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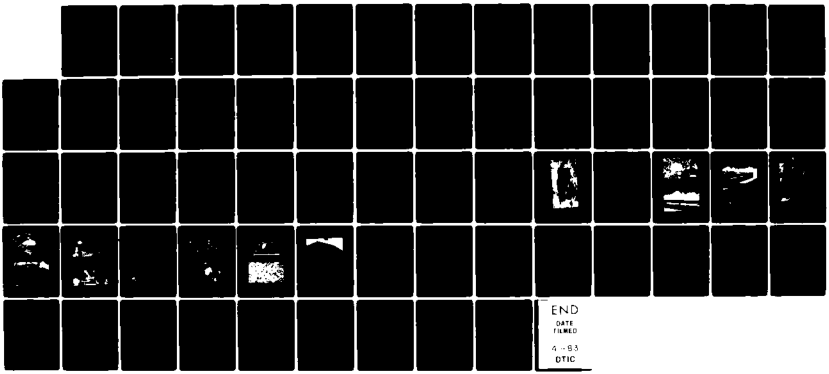

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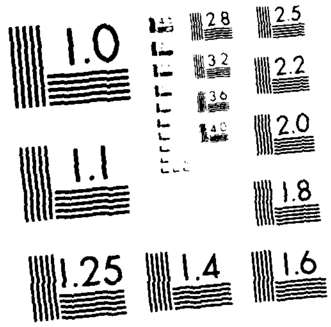
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AUTHOR: R. L. Alumbaugh, J. R. Keeton, and E. F. Humm

DATE: January 1983

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NOTE

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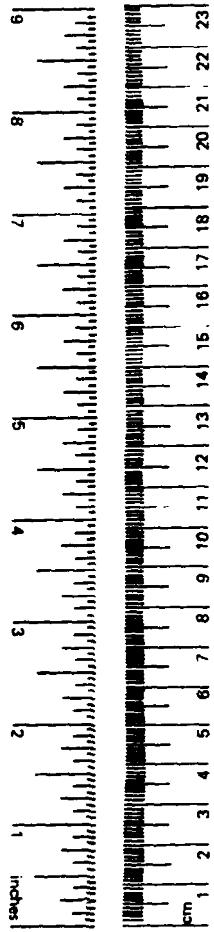
Dr. Robert L. Alumbaugh and Mr. John R. Keeton (now retired) are staff members of the Naval Civil Engineering Laboratory. Mr. Edwin F. Humm is the Roof Maintenance Consultant, Northern Division, Naval Facilities Engineering Command, Philadelphia, Pa.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

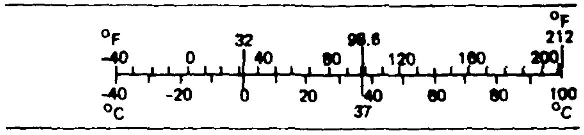
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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An experimental roofing installation is described in which polyurethane foam (PUF) was spray-applied directly to metal Butlerib-type metal decks, the roof divided into five approximately equal areas, and the PUF protected with five different elastomeric coating systems. Three of the coating systems were damaged by hailstones about a year after installation; these systems were recoated within 3 years of the initial installation. The current coatings include two of the original coating systems – a plural

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component silicone and a single component silicone -- and those applied over the three systems damaged by hail -- a single component silicone, an aluminum filled, hydrocarbon-extended catalyzed urethane, and a catalyzed urethane. The performance of these five PUF systems over a 7-year period is reported. The temperature distributions throughout the roof systems are described. The decay in the thermal conductivity of the PUF roof over a 5-year period is presented, and the energy savings realized by foaming the roof are presented.

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An experimental roofing installation is described in which polyurethane foam (PUF) was spray-applied directly to metal Butlerib-type metal decks, the roof divided into five approximately equal areas, and the PUF protected with five different elastomeric coating systems. Three of the coating systems were damaged by hailstones about a year after installation; these systems were recoated within 3 years of the initial installation. The current coatings include two of the original coating systems a plural component silicone and a single component silicone and those applied over the three systems damaged by hail a single component silicone, an aluminum filled, hydrocarbon-extended catalyzed urethane, and a catalyzed urethane. The performance of these five PUF systems over a 7-year period is reported. The temperature distributions throughout the roof systems are described. The decay in the thermal conductivity of the PUF roof over a 5-year period is presented, and the energy savings realized by foaming the roof are presented.

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CONTENTS

INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) has studied the use of spray-applied polyurethane foam (PUF) and protective coating systems since 1973. This is the fourth report describing results of studies of PUF roof systems at NCEL. The first of these described application of the spray-applied polyurethane foam (PUF) and protective coating systems to the roofs of the Naval Reserve Center (NRC), Clifton, N.J., (Ref 1). The second report described initial results of small scale field and laboratory tests directed toward developing performance criteria for optimum PUF roof systems, (Ref 2). The third report presents results of an investigation to determine the decay in the thermal conductivity of PUF roofs with time, (Ref 3).

Experimental study described in this report was initiated for the following reasons:

1. To evaluate the long-term weathering performance of spray-applied polyurethane foam and coating systems on metal roofs.

2. To determine energy savings made possible by the application of PUF to the roofs.

3. To determine the dynamics of heat transfer through the roofs.

4. To determine the long-term degradation in thermal characteristics of the spray-applied PUF, if any.

BACKGROUND

In addition to describing application of spray-applied polyurethane foam (PUF) and protective coating systems to the roofs of the Naval Reserve Center (NRC), Clifton, N.J., Reference 1 also showed: (1) replacement of isolated small sections of foam and coatings as well as an interim evaluation of the performance of the coating systems from Fall 1973 to Fall 1975, (2) details of installation of thermocouples to obtain a measure of the heat transfer through the roofs, (3) a summary of savings in heating costs due to the application of the foam, and (4) hail damage that occurred to the coating systems on the south building during a storm in the summer of 1975.

As shown in Figures 1 and 2, NRC Clifton consists of two Butlerib metal buildings, a "north" building, and a "south" building connected by a "boiler house." The north building is 162 feet long and 40 feet wide; the south building is 203 feet long and 40 feet wide. The two buildings are connected at about the midpoint by the boiler house, a small concrete block structure that contains the steam boiler and a connecting passageway. While both major buildings have attics, the attic in the north

building extends only about one-third of its length. The boiler house has a plywood roof deck over wood trusses, with wide selvage roll roofing over the plywood. To improve appearance, an aluminum gravel stop, authorized as a change order by the Resident Officer in Charge of Construction, was installed along the fascia edge of the roofline.

FOAM AND COATING SYSTEMS

Figure 1 also shows the original layout of coating systems and thermocouples. Roofs on the buildings were divided into five sections, and five different coating systems were applied to these sections. The same PUF product was used on all roofs to eliminate one variable. Selected properties for the spray-applied PUF used on these roofs are shown in Table 1.

The Appendix presents the trade names and sources of the materials used in this study. Descriptions of the coating systems are given in the following sections. Application data for all coating systems are summarized in Table 2.

Original Systems

System 1. Catalyzed Silicone Rubber. System 1 consists of one base-coat of a medium-gray, catalyzed silicone rubber and one top-coat of a cement-gray, catalyzed silicone rubber. The recommended application rate for both base coat and topcoat is 1 gal/100 sq ft to provide a nominal wet film thickness of 16 mils and a nominal dry film thickness of 10 mils. Minimum recommended dry film thickness of the total system is 20 mils. Because of the short pot life of the catalyzed system, application requires a special unit in which the two compounds are mixed in the spray gun just prior to leaving the nozzle. Gray ceramic granules were broadcast at the rate of 50 lb/100 sq ft into the wet topcoat on one-half of the area covered with System 1. The granules are supposed to provide a longer wearing, more durable surface. This coating system is referred to as "breathing" or "vapor permeable" because it allows passage of water vapor but not liquid water.

System 2. Moisture-Curing Silicone Rubber. System 2 consists of two coats of a single component moisture-curing silicone rubber. The recommended application rate for the light gray base coat and the white topcoat, identical except for color, is 1 gal/100 sq ft to provide a wet film thickness of 10 mils and a dry film thickness of 7.5 mils. Minimum dry film thickness recommended for the total system is 15 mils. This silicone coating system is also referred to as vapor permeable.

System 3. Catalyzed Butyl-Hypalon. System 3 consists of a two-component black catalyzed butyl base coat and a two-component white hypalon topcoat. The application rate recommended for the base coat of butyl was 2 gal/100 sq ft to provide a minimum wet film thickness of 20 mils and a minimum dry film thickness of 10 mils. Application of the catalyzed butyl base coat required special equipment for mixing the two components prior to leaving the spray gun. The two-component white

hypalon topcoat was batch-mixed (catalyst mixed with resin) prior to spray application; the recommended application rate was 1.5 gal/100 sq ft to provide a minimum wet film thickness of 8 to 9 mils and a minimum dry film thickness of 5 mils. Minimum dry film thickness recommended for the total system was 15 mils. This butyl-hypalon coating system was "nonbreathing" or "vapor impermeable," because it inhibited passage of both water vapor and liquid water. This product is no longer available.

System 4. Hypalon Mastic. This one-coat system consists of a single-component, white hypalon mastic; the recommended application rate is 6 gal/100 sq ft to provide a minimum wet film thickness of 90 mils and a minimum dry film thickness of 30 mils. This hypalon coating system is classed as vapor impermeable.

System 5. Catalyzed Butyl-Hypalon. System 5 consists of a two-component, cationically polymerized, tan butyl base coat and a one-component, white hypalon topcoat. The recommended application rate of the butyl base coat is 2.5 gal/100 sq ft to provide a minimum wet film thickness of 39 mils and a minimum dry film thickness of 18-1/2 mils. The two components of the butyl base coat are batch-mixed prior to spraying. The application rate recommended for the white hypalon top coat is 1 gal/100 sq ft to provide a wet film thickness of 12 mils and a dry film thickness of 4 mils. Minimum dry film thickness recommended for the total system is 22-1/2 mils. This butyl-hypalon system is classed as vapor impermeable.

Repaired Systems

Early failure of Coating Systems 3, 4, and 5, due in part to initial poor quality (Systems 3 and 4) and in part to hail damage, necessitated recoating of the south building and the boiler house in 1976. Descriptions of the new coating systems are given below.

The only surface preparation of the south building and boiler house roofs prior to recoating consisted of brooming and air blowing the roof surfaces to remove any dirt, loose coating, or chalk. The following coatings were then applied.

System 6. Moisture-Curing Silicone With Granules. This system is the same as System 2 except white granules were applied to the wet topcoat at the rate of 50 lb/100 sq ft. Application rates for the base coat and topcoat were the same as for System 2.

System 7. Catalyzed Hydrocarbon-Modified Urethanes. System 7 consists of a black base coat of 100% solids hydrocarbon-modified urethane and a topcoat of aluminum-filled hydrocarbon-modified urethane. The recommended application rate of the base coat was 3 gal/100 sq ft to provide a wet and dry film thickness of 40 mils, while the application rate recommended for the topcoat was at 1 gal/100 sq ft to provide a wet film thickness of 14 to 15 mils and a dry film thickness of 9 to 10 mils.

System 8. Catalyzed Urethane With Granules. System 8 consists of a urethane primer overcoated with a base coat of aluminum aromatic urethane and a topcoat of white aliphatic urethane. White mineral granules were applied to the wet topcoat. The recommended application rate of the primer was 3/4 gal/100 sq ft to provide a wet film thickness of 7 to 8 mils and a dry film thickness of 2 mils. The base coat application rate recommended was of 2 gal/100 sq ft to provide a wet film thickness of 30 mils and a dry film thickness of 15 to 16 mils. The recommended application topcoat rate was 1/2 gal/100 sq ft to provide a wet film thickness of 10 to 12 mils and a dry film thickness of 4 to 5 mils. White granules were applied at the rate of 50 lb/100 sq ft.

Current Status

Figure 3 shows the current layout of the coating systems.

The same moisture-curing silicone used in System 2 was used in the first section over the failed System 3 (catalyzed butyl-hypalon) on the south building. White roofing granules were applied to the white wet topcoat. This system is designated as System 6.

In the middle section of the south building and over the boiler house, System 7 (an aluminum-gray catalyzed urethane) was applied over the failed System 4 (hypalon mastic). No granules were used in this section.

System 8 (a white catalyzed urethane) was applied to the remaining section over the failed System 5 (catalyzed butyl-hypalon). White roofing granules were applied to the wet topcoat.

THERMOCOUPLE INSTRUMENTATION

Thermocouples of copper constantan wire were installed at various locations to study temperature distribution in the roof systems and inside the buildings and to determine the time-dependent insulation efficiency of the PUF. The thermocouple locations and their original numbers are shown in Figure 1.

Measurements of temperatures were made originally on a potentiometer located in a room at attic level in the north building. Reserve Center personnel read and recorded temperatures at about 0900 and 1400 daily between roof installation in October 1973 and June of 1978, when an automatic digital recorder was installed. Since the digital recorder has only 20 channels, it became necessary to select the most pertinent 20 channels for automatic hourly recording.

Figure 3 and Table 3 show the current thermocouple numbers and locations. Thermocouples referred to as "below the foam" in Table 3 were placed directly on the top surface of the steel roof deck before the foam was applied. Those referred to as "above the foam" were placed directly on the top surface of the foam; the coating was then applied over the thermocouples. Those placed in attic spaces were suspended about 4 feet from the underside of the roof. Thermocouples for measuring the outside air temperature were suspended several feet above the roof. Reference 1 represents a more detailed account of the original thermocouple and roof installation and roof system performance.

RESULTS AND DISCUSSION

Evaluation of Foam and Coating Systems

The condition and performance of the five different coated urethane foam roofing systems was determined during on-site inspections by NCEL and NAVFAC* Northern Division personnel. The inspections were conducted semiannually for the first 2 years and annually thereafter. The inspections consisted of walking all areas of the roofs and noting and photographing any deterioration of coatings or foam. Photomacrographs of selected areas were also taken during each inspection in order to have a progressive record of any deterioration. Once Systems 3, 4, and 5 had been damaged by hail and had been recoated, photomacrographs of specific areas were discontinued because the defects being photographed were covered and obscured by the new coating systems.

Ratings were assigned to each system during each inspection. Ratings and the definitions are explained as follows:

E = Excellent; the system is in excellent condition with little or no coating or foam deterioration.

VG = Very good, the system is performing very well and shows only minor coating or foam deterioration.

G = Good; the system is performing satisfactorily, but coating or foam deterioration is nearing a point of significance.

F = Fair; the system is showing moderate coating or foam deterioration.

P = Poor; the system has numerous areas showing moderate to severe coating or foam deterioration.

Results of the inspections conducted to date (up to 7 years of exposure) are presented in the following sections and are summarized in Table 4. Deterioration of quality PUF roof systems is ordinarily first noticeable in the coatings. Generally speaking, as long as the coating performs well, the foam can be expected to perform well also. In areas where the coating deteriorates or flakes off, the foam degrades from exposure to the weather. Thus, the ratings tend to reflect the condition of the coating system on the roof. It should be emphasized that even where the coatings have not performed well, either due to deterioration from exposure to the weather or from mechanical damage caused by such things as hailstorms, the experimental roof systems have not leaked since the foam was applied. These metal roofs had severe leaking prior to being foamed.

*Naval Facilities Engineering Command

System 1. Catalyzed Silicone Rubber

This system was divided equally into two sections: one with granules and one without granules.

Catalyzed Silicone With Granules. This portion has performed very well throughout the entire 7-year exposure period. For the first 3 years, the only deterioration noted was very light flaking of the coating from the foam, exposing the foam after 3 years of weathering. Some minor bird pecking which exposed the foam was also noted (see Figure 4). After 3 years, minor defects (1/4 to 1 inch in diameter) in the coating due to either flaking or bird pecking were given a minimum maintenance treatment by covering the exposed foam with silicone sealant and granules. This minimum maintenance, in essence, provided a coating with granules having very few defects.

In addition to minor damage by pecking, birds had also reached the foam by entering underneath the gravel stop in two areas. The birds had removed the foam and built nests under the coating in about 1 sq ft of each area; the coating was still intact. These areas were repaired by cutting away the coating, smoothing the edge of the pecked foam, and then protecting the smoothed edge with silicone coating. The configuration of the aluminum gravel stop caused the foam to ridge-up above the gravel stop edgeline, along the eave of the roofs, as the foam was applied. Such an edge detail is difficult to protect properly, and coating deterioration was observed all along the edge, exposing the foam to deterioration. However, this was not considered serious in the overall performance of the roof; after 3 years of exposure, the silicone with granules was rated E.

With additional exposure, the silicone with granules continued to perform very well and was rated VG to E at both the 4- and 5-year inspection periods. There continued to be isolated small spots of exposed foam (generally 1/4 to 1 inch in size) both by flaking of the coating and by bird pecking. Although the bird pecking was a minor problem, it does seem to be a persistent one, occurring only on the silicones. It is interesting that the pecking appeared to be slightly heavier on the silicone with granules than on the silicone without granules. At other installations, granules have tended to inhibit bird pecking.

This area was rated VG to E rather than E because of very light cracking of the silicone along the ribs of the Butlerib roofing. It appears that this type of problem occurs when the foam and coating are sprayed in only one direction. Spray application of individual lifts of the foam in alternate directions (i.e., crosshatching) and application of the coating in a similar manner tend to eliminate this problem.

After 6 and 7 years of exposure, the performance of the catalyzed silicone with granules was rated VG (see Figure 5). The slight lowering of the rating resulted primarily from the bird pecking problem and, to a lesser extent, from the light cracking of the silicone along the rib. It is believed that with a minimum of annual maintenance, this system will perform very well for at least 10 years before recoating is necessary.

Catalyzed Silicone Without Granules. This portion of System 1 has also performed very well for the 7-year exposure period, although not quite as well as the section with granules. This section experienced the same types of coating deterioration observed on the portion with granules; i.e., light flaking or spalling of the coating, bird pecking, flaking of coating from foam along the edge of the aluminum gravel stop where the foam had ridged, and light cracking of the silicone along the ribs. The bird pecking problem, which appeared to be the major cause of coating removal and exposure of foam, was slightly more severe on the portion with granules than on this section without granules. However, there appeared to be more flaking of the coating in this section than in the section with granules. Although the catalyzed silicone did show a very small amount of additional deterioration each year, the system performed very well and was rated very good from an age of 1-1/2 years through 7 years. It is believed that with a minimum of annual maintenance, this system also will perform well for another 2 to 3 years (total of 10 years) before recoating is necessary.

System 2. Moisture-Curing Silicone Rubber

This section of the experimental roofs has not performed as well as the section coated with catalyzed silicone, although the two systems performed similarly for about the first 3 years. The difference in long-term performance is attributed to two factors. First, the total dry film thickness of System 1 (30 mils) is almost twice that of System 2 (17 mils). Because of this, the coating of System 1 has been better able to take abuse from foot traffic and from snowloads as they slide off the roof. Second, foot traffic on System 2 has been much heavier than on System 1. An outside wall ladder and catwalk provide access to the roofs and exits onto the roof in the System 2 area (see Figure 6). The station's TV antenna is mounted at the crest of the roof and on the top of the catwalk. Anyone wanting to gain access to the roof to service the antenna, to perform other rooftop maintenance, or to inspect the roofing systems, must cross this silicone system. As a result, the rather excessive foot traffic on this section has taken its toll in damage to the coating system.

In some of the areas where foot traffic was heavy, the coated foam has been compressed, damaging the cell structure. In these cases, the damage frequently occurred on the foam covering the ribs of the roof deck because it was at a slightly higher elevation than the foam between the ribs. Where this occurred, the coating was sometimes loosened from the foam and could be peeled from the foam in a few small areas (i.e., 1 to 3 sq in. in size, (see Figure 7).

Although the 2-year rating (Ref 1) obviously differed from the 3-year rating, this system was still performing well after 3 years of exposure and was rated VG. Deterioration of the silicone coating consisted principally of bird-pecking and flaking of the coating, exposing the foam. Most of the damage was attributed to flaking of the coating. After 3 years, bird pecking did not appear to be as frequent on System 2 as on System 1. However, removal of the foam from underneath the coating by birds entering underneath the gravel stop was definitely more of a problem in this section than in System 1 (see Figure 8). Birds had removed the foam under the coating along the gravel stop in seven areas

within System 2. Six of these were along the northerly edge and only one along the southerly edge. All of these areas were easily repaired as noted in the discussion covering System 1; i.e., the coating was removed, the foam edge cut back to a smooth edge, and the smoothed foam coated with 2 coats of System 2 coating (moisture-curing silicone rubber coating). Water was not a problem to the foam because it drained onto the metal roof deck underneath the gravel stop and thence to the ground.

Flaking of the coating occurred in very small isolated areas 3/8-in. or less in diameter except for a few larger areas on the ribs where the foam had been damaged, causing the coating to loosen. The majority of flaking of the coating occurred along or on top of the ribs as shown in Figure 9. System damage caused by bird pecking, found only in isolated spots around the roof, generally ranged in size from 1/4 to 1 inch in diameter.

In addition to the deterioration noted above, in one very small area (3 to 4 sq in. in size), the foam was wet and exuded water when compressed (see Figure 10). It was evident that only a minimum amount of moisture was present in the foam since additional pressure did not cause any further exudation of water.

Continued weathering of System 2 resulted in slow, progressive deterioration of the coating by flaking and bird pecking, exposing the foam in isolated small areas to the degrading effects of sunlight and moisture. At the conclusion of both the 4- and 5-year exposure periods, the performance of the coated foam was not quite as good as at the 3 year inspection period but was still better than the criteria established for a rating of good. Thus, at both the 4- and 5-year inspection periods, System 2 was rated G to VG.

In addition to those instances noted, other forms of coating deterioration became more prominent. This consisted of two types of cracking of the coating. The first was damage caused by heavy foot traffic where heel impressions caused the coating to crack. The second also observed in System 1, was cracking along the rib as a result of alternate lifts or coats of the foam and coating being applied in only one direction rather than in alternate or crosshatched directions (see Figure 11). Such a crosshatch application pattern would have prevented the coating from cracking along the ribs. It is interesting that where cracking of the coating had occurred as a result of heavy foot traffic on the ribs, foam degradation underneath the crack was often minimal even after 5 years of weathering.

After 6 and 7 years of exposure to the weather in Clifton, N.J., System 2 exhibited more pronounced deterioration and was rated G and F to G, respectively, for those years. Types of deterioration were generally the same as noted previously. In addition, in two small areas the foam had delaminated (blistered) lift from lift. Approximately 75% of the spalling of the coating occurred on the ribs. The northwesterly and southwesterly portions of this system should receive more extensive maintenance (e.g., removal and replacement of degraded coating and foam where required). The remaining area of this system should be patched and recoated and granules applied to the wet topcoat.

As noted earlier, this silicone tends to retain dirt and give the roof a very dark gray appearance. A few spots were scrubbed with a GI brush and trisodium phosphate detergent. These areas, including some

spots over thermocouples, cleaned up very well, giving a surface nearly as white as when originally applied.

Systems 3, 4, and 5

These systems were recoated due to hail damage, and the recoated systems renumbered as Systems 6, 7, and 8, respectively. The performance of these latter systems are described below.

System 6. Moisture-Curing Silicone With Granules

This silicone coating with granules had been applied over the hail damaged and deteriorated catalyzed butyl-hypalon system (originally System 3). The butyl-hypalon system had been badly cracked by the hailstones, and these cracks tended to be reflected through the silicone coating; that is, the silicone coating did not bridge the cracks (see Figure 12). However, because of the hydrophobic character of the silicones, the cracks may not permit water migration into the foam; additional exposure will determine this factor. The silicone had just been applied a few months prior to the 3 year inspection period and was rated VG to E.

At the 4-year inspection period (approximately 15 months after recoating), the hailstone cracks in the coating were still evident, although it now appears that the silicone did bridge some of the cracks in the original butyl-hypalon coating. The coating has spalled from the foam in about 20 to 25 spots. It appears that the spalling may be attributed to hailstone damage. The surface cellular structure of the foam appeared to have been damaged by the hailstones, and the stresses that developed in the coating as it weathered exceeded the cohesive strength of the damaged foam, and the coating and surface foam spalled from the roof. Also bird pecking is slightly evident but this is not at all serious, and at the 4-year inspection period this recoated system was rated VG to E.

At the 5-year inspection period (approximately 27 months after recoating), the hailstone cracking, spalling of the coating, and bird pecking were more prevalent. Spalling of the coating was observed principally on top of the ribs. In addition, a small area of foam delamination about 3/4 sq ft in size and a few blisters were observed in the silicone coating. These however, were not considered serious defects, and the system was still rated as VG.

With continued exposure, deterioration of the system became more severe. Evidence of hail damage (cracking of the coating) on top of the ribs became more obvious, and slight deterioration of the foam (sponginess) was noted. More bird pecks were found, particularly on the southerly roof surface. The area of foam delamination on the northerly roof surface had grown to a size of 1- to 1-1/2 sq ft (see Figure 13), and a second small foam blister approximately 4 inches in diameter was observed on the southerly surface. As this small blister formed, both the coating and the surfaces of the foam exhibited cracking. At the sixth year inspection, (approximately 39 months after recoating) the system was rated G.

During the seventh year inspection period (approximately 4 years after recoating), all of the forms of deterioration noted earlier had increased in severity. The amount of foam delaminated had grown to approximately 2 sq ft. The system was rated F to G and is in need of more extensive maintenance.

System 7. Catalyzed Hydrocarbon-Modified Urethane

This coating system was applied over the hail-damaged and severely weathered hypalon mastic of System 4. This new system, consisting of a thick, black base coat and an aluminum-filled topcoat, should have exhibited a bright, reflective aluminum color. However, because of either poor material properties or poor application (or both), the surface exhibited a very blotchy appearance caused by "bleeding" of the black base coat through the aluminum topcoat. In many cases, the topcoat was too thin and had not flowed properly to completely hide the black base coat, resulting in an orange-peel effect. In other areas the topcoat was applied too heavily, causing it to run or sag.

In the area where the boiler house roof joined the roof of the south building, numerous blisters (approximately 15) formed, ranging in size from 1 to 4 inches in diameter. Three of these blisters are shown in Figure 14. The blisters occurred both between the old and new coatings and between the very thin (1/8-inch thick) top and adjacent lifts of foam, and in some cases were attributed to the presence of moisture. Because of the toughness of the new coating system, the blisters caused no problem.

This coating system, probably because of its thickness, did bridge the hailstone cracking in the hypalon mastic coating but did not bridge those areas on the southerly portion of this system where the old coating had spalled and the foam had degraded to a limited extent. In spite of the application problems, this system was providing very good protection to the foam. After 3 years (approximately 3 months after recoating), this system was rated VG to E.

During the 4-year rating period (approximately 15 months after recoating), this system still provided relatively good protection to the PUF and was rated VG. In addition to the original appearance items noted, a number of black pinholes appeared to be developing that penetrated through the entire coating system (see Figure 15). The topcoat also developed a crazing or line checking which added to the blotchy appearance of the surface as shown in Figure 16. In addition, an unusual type of blistering or ridging of the topcoat appeared on the southerly portion of the roof, some of which resulted in light peeling of the topcoat from the base coat (see Figure 17).

Continued exposure appeared to cause an increase in the number of black pinholes. The pinholes range in size from quite small to about 1/8-in. in diameter. Two of these exuded a small amount of water when the foam was compressed. The size of the blisters also continued to increase. In one case, the blister was about 25 sq in. and was formed between the hypalon mastic coating and the hydrocarbon-modified urethane base coat. The appearance of the system as well as the performance continued to deteriorate. Crazing and ridging or blistering of the topcoat

became more severe, and at the 5-year inspection period (approximately 27 months after recoating), the system performance was rated G.

Deterioration of the hydrocarbon-modified urethane coating/PUF roofing system became progressively worse during the sixth and seventh year exposure periods (approximately 3 and 4 years after recoating, respectively). Additional moisture was observed in the foam, generally exuding from the black pinholes when the adjacent foam was compressed. A gradient of rings appeared around the black holes, suggesting that each of the holes contained water at some time, even though some were dry when inspected. The black pinholes may have been caused by the presence of moisture on the existing deteriorated hypalon mastic coating when the hydrocarbon-modified urethane coating was applied. There appeared to be more and larger blisters, and the coating over some of these was starting to crack (Figure 18). The surface crazing or checking tended to become more pronounced. As a result, this system was rated F to G after 6 years, and P to F after 7 years of weathering, and was in need of extensive maintenance.

System 8. Catalyzed Urethane with Granules

This elastomeric urethane coating system was applied over the existing System 5, a butyl-hypalon coating that had been damaged by a hailstorm. While the coating had numerous breaks caused by the hailstones (see Figure 19), this butyl-hypalon coating was performing most satisfactorily prior to the hailstorm; i.e., it was still protecting the PUF from exposure.

The catalyzed urethane elastomer coating system did not bridge many of the cracks in the butyl-hypalon system. This cracking, which was obvious both before and after coating, was most severe on the northeasterly side, with very little cracking noted on the southerly side. The cracking, was the only form of deterioration observed with this system. Although the cracking opened a path for sunlight and moisture, very little degradation of the foam was observed. This system has continued to perform very well during the third, fourth, and fifth year inspection periods (approximately 3, 15, and 27 months after recoating). This system was still providing superior protection to the foam and was rated VG to E. With continued exposure, the cracks appeared to open slightly but the foam showed little, if any, additional degradation (see Figure 20). The system continued to perform very well, and after 6 to 7 years of weathering (approximately 3 and 4 years, respectively, after recoating), was rated VG.

Thermal Characteristics of Spray-Applied PUF

As stated earlier, one of the purposes of this experiment was to determine the effect of time on the thermal conductivity (k) of spray-applied foam. The manufacturer of the PUF stated that when freshly sprayed-in-place, his product had a k value of 0.13 Btu/hr sq ft °F in.

After 5 years, samples were taken from each section of the roofs at the Reserve Center. From these samples, specimens were prepared for measurement of k in a Thermal Conductivity Analyzer, Model 88 (Anacon, Inc.). Table 5 shows results of the tests as well as foam thickness and

thermal resistance (R) calculated from the k values. Table 5 also indicates the percent change in k-values in 5 years, based on the manufacturer's stated k-value of 0.13. Roof sections with coating Systems 1 and 2 (north building) showed the most change in k. Significantly less change occurred in the roof sections on the south building (Systems 6, 7, and 8). Additional data on the thermal conductivity of these samples as well as weathered foam samples from other locations are given in Reference 3.

The significant characteristics which provides PUF with excellent thermal resistance is its formation of essentially closed cells containing freon. It has been determined that the freon gradually migrates from the cells and is replaced by air, causing a reduction in thermal resistance with time. Manufacturers of PUF contend that the thermal resistance eventually stabilizes, and no further losses ensue.

The original coating Systems 3, 4, and 5 on the south building (see Figure 1) were all classed as impermeable to passage of water and water vapor. Systems 3 and 5 were catalyzed butyl-hypalon, and System 4 was hypalon mastic. System 3 was a poor quality coating system which deteriorated rapidly and was providing very poor protection to the foam when it was recoated in 1976.

Most likely, the high resistance of the impermeable coatings to passage of water vapor reduces or impedes passage of freon gas from the PUF which results in less overall loss of thermal resistance from the roof sections on the south building. Although the coating of System 3 was providing little protection when it was recoated, it had furnished a fair degree of impermeability to the passage of freon gas for the first 3 years. This accounts, in Table 5, for the smaller rise in k-value in the section of coating System 6 than in the sections of Systems 1 and 2. When the south building was recoated, the existing coating systems were not removed. The underlying hypalon of System 4 and the butyl-hypalon of System 5 are therefore still providing some degree of resistance to the loss of freon. The new coatings applied to the south building and the coating systems on the north building are all permeable coatings.

Heat Transfer Characteristics

As stated before, temperature readings were automatically recorded hourly on the hour. Figure 21 is a typical plot of hourly temperatures for July 13, 1979 in the moisture-curing silicone section with granules (System 6). The time-temperature envelope is determined by measuring the area under each of the curves with respect to selected datum lines. With the assumption that the temperatures a roof experiences result from exposure to the sun, then the outside air temperature (solid squares in Figure 21) is a measure of the intensity of the sun for a given day influenced directly by clouds and windspeed. Accordingly then, the area ABCDA in Figure 21 can be called a measure of the "solar heat response," since this area represents how much the temperature on top of the foam (open circles) exceeds the outside temperature (solid squares) in the day-time hours of highest solar intensity (i.e., between 0800 and 2000). The solid triangles in Figure 21 are the temperatures just below the foam. Assuming that 75°F is a reasonable room temperature for summer

and drawing a horizontal line at that temperature, then the area EFGHJE represents a measure of the "cooling required" for the hotter portion of that day.

Outside air temperatures over the entire day not only indicate relative heat or sun intensity, but also reflect the effects of cloud cover, windspeed, and radiation from the roof during early morning and late evening hours. Measurement of the area under the outside temperatures (solid squares) with respect to a datum temperature of 0°F, then, represents a measure of the overall temperature severity of that day. The "outside temperature area" for the hotter portion of the day may be obtained by measuring the area KLDMNK and adding it to the area from 40° to 0°F for 0800 to 2000. A summary of these relative energy factors defined by the measured areas under the temperature curves (i.e., outside temperature area, solar heat response, and cooling required) together with the highest roof temperatures for selected days are given in Table 6.

All hourly temperatures for each day were plotted on graph paper, and areas were measured with a compensating polar planimeter that reads to four digits. One square inch measured 100. Each area was measured three times to minimize errors and to obtain an average.

Solar Heat Response. Solar heat response for selected days during the summer of 1978, 1979, and 1980 are listed in Table 6 (Columns 2 through 7). Column 22 shows the outside temperature area between 0800 and 2000 listed in order of severity of daytime temperatures: the higher the outside temperature area, the hotter the day.

Figure 22 shows solar heat response for the System 1 sections. The lines drawn are approximate least squares lines for the points shown. They are drawn only to indicate trends and do not imply that they are representative of all possible points of solar heat response. The only difference in the top surfaces of the two sections shown in Figure 22 is that the left portion has granules and the right portion does not. Points plotted in Figure 22 are listed in Columns 2 and 3 of Table 6.

Solar heat response for Systems 2 and 6 (both moisture-curing silicone) are shown in Figure 23. The top surface of System 6 has granules, and System 2 does not. Points plotted in Figure 23 are listed in Columns 4 and 5 of Table 6. Figure 24 shows solar heat response for Systems 7 and 8. Points plotted are listed in Columns 6 and 7 of Table 6.

Figure 25 shows all the least squares lines from Figures 22-24. System 8, white catalyzed urethane with white granules, shows the lowest values of solar heat response. This coating system maintained its original white color longer than any of the other coatings. The highest values were in System 2, moisture-curing silicone without granules. Although this coating system was originally white, the silicone top surface soon began to soil and within a few months it had become a dingy gray. When the coatings were first sprayed, roof temperatures at the top surface (above the foam) were about 20° to 30°F cooler in the white silicone of System 2 than in the gray catalyzed silicone of System 1. In a few months, however, the top surface temperatures were almost the same in the two coatings, due to the darkening of the moisture-curing silicone of System 2.

The second lowest solar heat response in Figure 25 was in System 6 which is the same moisture-curing silicone used in System 2, the difference between the two systems being the white roofing granules applied in System 6. Graying of the top surface of System 6 has been much less severe than in System 2, partly because the white roofing granules do not discolor and partly because the presence of the granules reduces the exposed surface area of the silicone. Figure 25 indicates that all three of the gray coating systems (1 with and without granules, and 7 without granules) show about the same values of solar heat response. It should be emphasized that solar heat response is a direct measure of the effect of the sun's heat upon the roof.

Cooling Required. Figure 26 shows cooling required on System 1 sections. As before, the lines drawn are approximate least square lines for plotted points, taken from Columns 8 and 9 of Table 6. Cooling required on Systems 2 and 6 are presented in Figure 27; points plotted are taken from Columns 10 and 11 of Table 6. Figure 28 shows cooling required on Systems 7 and 8, taken from Columns 12 and 13 of Table 6. Least-squares lines of cooling required for all sections are shown in Figure 29. System 7, aluminum-gray catalyzed urethane without granules, indicates the least cooling required of all sections and System 2 shows the most, although variation among them is not very wide.

The relationships shown in Figure 29 reflect interplay between the reaction of the roof system to the sun's heat, as measured by solar heat response, and the insulating efficiency or thermal resistance (R) of the foam in each roof section. The last column of Table 5 shows thermal resistance (R) in each section: the higher the R-value, the greater the insulating characteristics of the material. System 7 has the highest R-value and the lowest cooling required in spite of a moderate solar heat response. In Table 5, System 8 has the second highest R-value. System 8 indicates the lowest solar heat response in Figure 25 but shows a moderate value of cooling required in Figure 29. System 1, with and without granules, shows the lowest R-values in Table 5 but shows moderate values of both solar heat response in Figure 25 and cooling required in Figure 29. System 2 (without granules) indicates a relatively low R-value in Table 5, and shows the highest solar heat response and cooling required. System 6 indicates a moderate R-value in Table 5 but shows the second lowest solar heat response and a moderate cooling required.

Highest Roof Temperatures. Columns 14 through 19 of Table 6 list highest daily roof temperatures in the various sections. On most days, the highest temperature occurred in System 2 (moisture-curing silicone without granules), Table 6, Column 17. As stated before, System 2, although white when sprayed, soon became dirty gray. Of all the days shown in Table 6, the highest temperature occurred in systems other than System 2 (Column 17) on only 5 of the listed days. In lines 2, 15, and 16, the highest temperatures occurred in System 1 with granules (Column 14) while in lines 11 and 14, it was in System 1 without granules (Column 15); both are gray coating systems. Except for 1 day, line 16, the lowest temperature was in System 8, (Column 18), which retained the brightness of its original white color after several years.

Except for those that chalk, most roof coatings tend to accumulate dirt as they age, some more than others. The silicone coatings used in this study have an inherent property to accumulate dirt more rapidly and to a greater extent than did the other generic types of coatings utilized. The white topcoat of the moisture curing silicone without granules (System 2) became a dirty gray color within the first year after spraying. As stated earlier, the highest roof temperatures usually occurred in System 2. Figure 30 shows roof temperatures in Systems 2 and 8 for July 13, 1979, a typical day of rather high heat intensity. Above-the-foam temperatures were highest in System 2 and lowest in System 8; the other systems were between these extremes. Figure 21 shows roof temperatures in System 6 for the same day.

To illustrate and emphasize the effects of whiteness of coating surface on roof temperatures, the dirty gray surface over the thermocouple in System 2 was washed with detergent to restore the white color, and allowed to dry. Typical roof temperatures before and after washing are shown in Table 7, arranged in day groupings of approximately the same heat intensity for reasonable comparison. On the hottest days a difference in temperature of 50° to 60°F was not uncommon.

Energy Savings

One of the purposes of this experimental roofing installation was to determine the savings in fuel consumption furnished by the urethane foam insulation. Table 5 shows thermal resistance values for the roofs. Since only one or two rooms of the Reserve Center are air-conditioned during hot weather, meaningful comparisons of fuel consumption before and after application of the foam are limited to usages of natural gas for heating in the colder seasons of the year. The requirement for heating can be expressed in terms of the number of degrees that the average daily temperature falls below 65°F; i.e., it is assumed that heat is required whenever the temperature is less than 65°F. For example, if on a given day the average temperature is 40°F, the degree day calculation is 65 minus 40 or 25. Since the time period is 1 day, this is commonly expressed as "25 degree-days." It is often convenient to compare these figures on a monthly basis, so the sum of the degree-days for each day of a given month is the "monthly degree-days." Because the concern here is natural gas consumption for heating, the figures used are called "heating monthly degree-days": the higher the number of heating monthly degree-days, the more severe the weather.

Table 8 shows the heating monthly degree-days for 2 years before and 8 years after installation of the foam. The average values shown on the bottom line of Table 8 reveal that the weather was consistently more severe in the 8 years after foaming than it was in the 2 years before foaming.

Table 9 lists the natural gas consumption in cubic feet on a monthly basis, both prior to foam installation and after foam installation. The October through May totals are averaged for the 2 years prior to foaming (476,100 cu ft) and totalled for the years following foaming. Table 9 also indicates the yearly reductions in gas usage compared to the 2-year average monthly usage prior to foaming. For a period of 8 years following installation, the foam roofs have provided a yearly average reduction of about 54% in heating gas consumption.

The average annual fuel usage was reduced from 3.869 x 10^6 cu ft prior to foam application to an average of 1.765 x 10^6 cu ft for the eight years following foam application. This results in an annual savings of 2.104 x 106 cu ft of natural gas saved per year. Each cubic foot of natural gas at Clifton is estimated to contain 1,031 Btu of energy. Thus the annual savings in energy is 2.104 x 10^6 cu ft x 1,031 Btu or 2.169 x 10^3 MBtu/yr.

The roof area at NRC Clifton totals about 16,600 sq ft. It is estimated that the Navy has about 35 x 10^6 sq ft of metal roof decks, including ribbed, corrugated and fluted units, at shore installations that could be foamed to reduce heating energy losses. Based on the energy savings at NRC Clifton, the Navy could realize an annual savings of 2.169 x 10^3 MBtu/yr x 35 x 10^6 sq ft/16.66 x 10^3 sq ft or 4.556 10^6 x MBtu/yr if all of the estimated 35 x 10^6 sq ft of metal decks were foamed. At a cost of $9.07/MBtu for natural gas, this would provide a potential annual savings to the Navy of about 41 million dollars.

Flammability and Fire Safety

Much comment has been made about the flammability and fire safety of polyurethane foam roofing systems and many horror stories have been disseminated about potential fire problems with these materials. In actual fact, very few problems with fire on PUF roofs have occurred as long as proper fire-classified systems have been employed. NCEL has always maintained that PUF roofs should meet the same fire requirements as any other roofing system. That is, the PUF systems employed should have the same Underwriters Laboratories (UL) or Factory Mutual (FM) classifications as required for conventional roofing systems.

Guidance in this area is provided by the DOD Construction Criteria Manual 4270.1M and NAVFAC Design Manual DM-8, Fire Protection Engineering. For combustible and metal roof decks the Construction Criteria requires that "the entire roof construction assembly, including the insulation, be Underwriters Laboratories listed as Fire Acceptable or Factory Mutual approved for Class I roof deck construction." This is not required if the insulation is installed above poured-concrete or poured-gypsum roof decks, nominal 2-inch-thick tongue-and-groove wood plank roof decks, or (over) precast roof deck panels or planks which are Factory Mutual approved as noncumbustible roof deck construction. In such cases, only UL 790 is required. NAVFAC DM-8 is more specific, requiring that (1) all roof coverings be approved and listed by UL under UL 790, top-of-the-roof fire safety classification, and (2) all roof deck assemblies, to be acceptable from an interior fire exposure standpoint, be listed as Class I in the FM Approval Guide or as fire classified in the UL Building Materials Directory (Roof Deck Construction Classification). Neither require a particular flamespread rating but a Class II foam (flamespread of 75 or less) is recommended.

Currently there are numerous (well over 100) PUF systems classified by UL under UL 790. Thus, a variety of PUF systems are readily available that are classified as fire safe under the same criteria that is used for conventional roofing. In addition, NCEL has conducted extensive fire testing of these PUF systems for use when applied directly to

metal or steel decks. These tests have shown that PUF systems exposed to fire are no more, and often less, of a problem than conventional roofing.

The NCEL-sponsored fire tests at UL have resulted in Roof Deck Construction classifications for PUF systems applied directly to (1) Butlerib metal decks (Ref 4), Roof Deck Construction No. 136 and (2) corrugated metal decks, Roof Deck Construction No. 181. Most recent successful tests at UL will result in classifications for foam over fluted metal decks. Roof Deck Construction No. 136 currently has some 30 different PUF roof systems listed as fire classified while Roof Deck Construction No. 181 has approximately five different PUF systems listed as fire classified.

Findings and Conclusions

The following findings and conclusions are presented on the basis of 7 to 8 years of weathering of the five different PUF roofing systems at NRC Clifton:

1. A 30-mil-thick silicone coating (System 1) with mineral roofing granules adhered in the topcoat can be expected to perform very well and provide very good protection to the sprayed PUF for up to 7 years with only minor maintenance requirements. This system should perform well for at least 10 years before recoating is necessary.

2. A comparison of the two silicone coatings (Systems 1 and 2) shows the effects of different film thicknesses on performance. Other experiments have shown that when applied at the same thickness, these two systems generally are similar in performance. This suggests that the silicone of System 2 would also perform very well for a similar period of 7 to 10 years if applied over sprayed PUF to a dry film thickness of 30 mils with mineral roofing granules adhered in the topcoat. The difference in performance of Systems 6 and 1 is attributed to the extremely poor condition of the original butyl-hypalon system (System 3) over which System 6 was applied.

3. A two-component urethane with mineral roofing granules adhered in the topcoat can be expected to perform very well for at least 5 years with essentially no maintenance.

4. A recoating thickness of 25 mils is not sufficient for a new coating to bridge cracks and spalled areas of a hailstone-damaged PUF roofing system.

5. The new coating Systems 6, 7, and 8 appeared to adhere well to the weathered and damaged coatings of Systems 3, 4, and 5. The only exception was some blistering in System 7 which was attributed to moisture in the existing System 4 when System 7 was applied. These results suggest that in some cases, brooming and air blowing of all loose dirt and dust from the surface may be sufficient surface treatment for recoating.

6. The thermal conductivity (k) of spray-applied PUF protected with a permeable coating averaged 0.177, while k for those systems having impermeable coatings averaged only 0.147. The k-values for individual PUF roofs increased as much as 37% or as little as 8.5% in 5 years for the permeable and impermeable coatings, respectively. This suggests that in more severe climates, such as Clifton, N. J., impermeable coating systems may retard decay of the thermal conductivity of a foam roof system more than permeable coating systems when applied at the same thicknesses as those used in this experiment.

7. Spray-application of PUF to Butlerib steel roofs like those at NRC Clifton can result in an average annual saving of 54% in natural gas consumption for heating. Based on an estimated 35 x 10^6 sq ft of Navy metal roof decks that could be foamed, this translates to a potential annual savings of 4.556 x 10^6 MBTU in energy with a projected cost savings of about 41 million dollars.

8. The solar heat response is principally a function of the sun's intensity and the relative absorption of the roof surface.

9. The cooling required is a function of the roof top surface temperature and the thermal resistance (R) of the foam.

10. Although it was more obvious on the white topcoat of System 2 than on the gray topcoat of System 1, both silicone coating systems accumulated dirt rapidly after installation. System 2 showed the highest roof surface temperatures of any of the coating systems. When the surface of System 2 over the thermocouples was scrubbed with trisodium phosphate and water, the dirt accumulation was easily removed and the white reflective topcoat was again evident. As a result of this cleaning, the top surface temperatures were reduced as much as 60°F. The lowest roof surface temperature most often occurred in the white catalyzed urethane with white mineral roofing granules adhered in the topcoat (System 8).

RECOMMENDATIONS

It is recommended that:

1. For energy conservation in accordance with DOD construction criteria, roofs of noninsulated Butlerib buildings which require heating or cooling should be insulated with at least 2-1/2 inches of spray-applied PUF protected with an appropriate coating system. The system utilized should have UL Roof Deck Construction classification under Roof Deck Construction No. 136 or appropriate FM classification for fire within a building as required in DOD construction criteria manual 4270.1M and NAVFAC DM-8, Fire Protection Engineering.

2. To minimize solar absorption, the topcoat of the coating system should be either a light color or contain white or light-colored roofing

granules. White or light-colored roofing granules also tend to minimize dirt accumulation, improve appearance, and provide a measure of mechanical protection to the coating system.

3. Silicone coating Systems 1 and 2 should be applied at a minimum dry film thickness of 30 mils with mineral roofing granules adhered in the topcoat.

4. A catalyzed urethane coating system similar to System 8 should be utilized when toughness is required in the coating system. Such a catalyzed urethane should be applied to a minimum dry film thickness of 25 to 30 mils, either with or without mineral roofing granules.

5. Impermeable coating systems should be employed for protecting PUF roofs in climatic regions similar to Clifton, N. J., in order to retard the decay in the thermal conductivity of the PUF.

6. Areas of Systems 2, 6, and 7 should be maintained by removing degraded foam and coating where necessary and refoaming or recoating as required.

7. PUF roof systems should have a UL790 classification for top-of-roof fires.

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Table 1. Selected Properties for Urethane Foam Used at NRC Clinton

Performance Criteria	NBS Criteria	Manufacturer's Data for Foam Selected	CEL Test Results	Test Method
Fire Safety	UL Class B	UL Class A, B, or C when properly coated	none	UL 790 ASTM E 108-58
Closed cell content (%)	>90	>90	none	ASTM D 2856-70 ASTM D 1940
Water absorption (lb/sq ft)	<0.02	0.10	none	ASTM D 2842-69
Water vapor permeability (perm-in.)	<3.0	2.0	none	ASTM C 355-64
Tensile strength, perpendicular to rise (psi)	>25	28	45	ASTM D 1623-64
Shear strength, parallel to rise (psi)	>25	22	none	ASTM C 273-61 (renewed 1970)
Density (lb/cu ft)	>2.0	2.0	2.3	ASTM D 1622-63 (renewed 1970)
Compressive strength, parallel to rise (psi)	>30	25	40	ASTM D 1621-64
Coefficient of linear thermal expansion (in./in./°F)	< 40×10^{-6}	60×10^{-6}	none	NBS Test Procedure for BUR Membranes
Volume change (%)				ASTM D 2126-66
At 40°F, ambient RH for 1 week	+3		none	
At 140°F, ambient RH for 1 week	+5		none	
At 158°F, 100% RH for 1 week	+12		none	
At 160°F, ambient RH for 4 weeks		+6	none	
At 160°F, 100% RH for 4 weeks		+15	none	
K-value (Btu/sq ft-hr-°F-in.)	none	0.11 to 0.14	none	ASTM C 177-71

Table 2. Application Data for Elastomeric Coatings

System Number and Description	Number of Coats	Nominal Film Thickness (mils) Wet	Dry
1. Catalyzed Silicone Rubber			
Medium Gray Basecoat	1	25	12.5
Cement Gray Topcoat[a]	1	35[b]	17.5
Total			30
2. Moisture-Curing Silicone Rubber			
Light Gray Basecoat	1	13[b]	6.5
White Topcoat	1	22	10.5
Total			17
3. Catalyzed Butyl-Hypalon			
Black Butyl Basecoat	1 to 2[c]	24	7.5
White Hypalon Topcoat	1	14	3.5
Total			11
6.[d] Moisture-Curing Silicone Rubber			
Light Gray Basecoat	1	10[b]	7.5[b]
White Topcoat[a]	1	10[b]	7.5[b]
Total			15[b]
Total of Systems 3 and 6			26[b]
4. Hypalon Mastic			
White Hypalon Mastic	1 to 2[c]	95	32
Total			32
7.[d] Catalyzed Hydrocarbon Modified Urethane			
Black Hydrocarbon Modified Urethane Basecoat	1	40+[b]	40[b]
Aluminum-Filled Hydrocarbon Modified Urethane Topcoat	1	15[b]	10[b]
Total			50[b]
Total of Systems 4 and 7			80[b]
5. Catalyzed Butyl-Hypalon			
Tan Butyl Basecoat	1	50	22
White Hypalon Topcoat	1	16	4
Total			26
8.[d] Catalyzed Urethane			
Urethane Primer	1	8[b]	2[b]
Aluminum Urethane Basecoat	1	30[b]	15[b]
White Urethane Topcoat[a]	1	10[b]	4[b]
Total			21[b]
Total of Systems 5 and 8			47[b]

[a]Mineral roofing granules sprinkled in wet topcoat at approximately 50 lb/100 sq ft.

[b]Film thickness estimated.

[c]A second light coat was applied in some areas where coating thickness was below minimum.

[d]These were new systems that were applied over existing systems damaged by hailstorm.

Table 3. Current Location of Thermocouple Stations

(See Figure 3)

Thermocouple Number	Coating System	Coating Color	Location
0, 1	Catalyzed Silicone (System 1) With Granules	Gray	Above and below foam, north building
2, 3	Catalyzed Silicone (System 1) Without Granules	Gray	Above and below foam, north building
4, 5, 6	Moisture-Curing Silicone (System 2) Without Granules	White	Above and below foam and in attic, north building
7, 8	Moisture-Curing Silicone (System 6) With Granules	White	Above and below foam, south building
9, 10, 11, 12	Catalyzed Urethane (System 7) Without Granules	Gray	Above and below foam and in attic, south building
13, 14	Catalyzed Urethane (System 8) With Granules	White	Above and below foam, south building
15, 16, 17	Catalyzed Urethane (System 7) Without Granules	Gray	Above and below foam and in attic, boiler house
18			Outside air, north building
19			Outside air, boiler house

Table 4. Performance of Coated Polyurethane Foam Roofing Systems

System Number and Description	Performance Rating[a] After: 0.5 yr	0.75 yr	1.5 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	Remarks
1. Catalyzed Silicone Rubber										The coating with granules in better condition than without. Some bird pecking in both sections. Overall system performing very well.
With Granules	E	E	E	E	E	VG to E	VG to E	VG	VG	
Without Granules	E	VG to E	VG	VG	VG	VG	VG	VG	VG	
2. Moisture-Curing Silicone Rubber	E	VG to E	VG	VG	VG	G to VG	G to VG	G	F to G	Performance very comparable to System 1 for first 3 years after which its lower film thickness & higher density of foot traffic caused further deterioration. Requires maintenance.
3. Catalyzed Butyl Hypalon	G	F	P to F	P	--	--	--	--	--	Original coating was near failure due to severe checking, cracking, erosion & hail damage when recoated.
4. Hypalon Mastic	VG to E	G to VG	G	P to F	--	--	--	--	--	Original coating severely damaged by hail and badly eroded on southerly side of roof.
5. Catalyzed Butyl Hypalon	E	VG to E	VG	F to G	--	--	--	--	--	Original coating moderately damaged by hailstones but performing well otherwise.
6. [b]Moisture-Curing Silicone Rubber (same as System 2 With Granules	--	--	--	--	VG to E	VG to E	VG to E	VG to G	F to G	Silicone coating did not bridge hailstone cracks in original coating. Because of the cracking and condition of original coating when recoated, system performing only moderately well.
7. [b]Catalyzed Hydrocarbon Modified Urethane	--	--	--	--	VG to F	VG	G	F to G	P to F	New coating bridged cracks but has not performed well. Did not bridge areas where original coating had spalled. Has exhibited blistering. Many pinholes are obvious and foam is wet in spots. Requires maintenance.
8. Catalyzed Urethane With Granules	--	--	--	--	E	VG to E	VG to E	VG	VG	New coating did not bridge hailstone cracks in original coating but is providing very good protection to the foam, nevertheless

[a]Ratings were as follows: E = Excellent; VG = Very good; G = Good; F = Fair; and P = Poor.
[b]Systems 6, 7, and 8 are new systems that were applied over hail-damaged, Systems 3, 4, and 5, respectively

Table 5. Thermal Factors for Each Roof Section

Coating System	Foam Thickness (in.)	Thermal Conductivity[a] (k)	Difference[b] (%)	Thermal Resistance[c] (R)
1[d]	2	0.178	36.9	11.2
1	2-1/4	0.178	36.9	12.7
2	2-3/8	0.174	33.8	13.7
6[d]	2-1/2	0.158	21.5	15.9
7	2-3/4	0.143	10.0	19.2
8[d]	2-1/2	0.141	8.5	17.9

[a] Thermal conductivity (k) = Btu/hr ft^2 $^{\circ}F$ in.

[b] From original k-value stated by manufacturer - 0.13.

[c] Thermal resistance (R) = $ft^2 hr$ ^{O}F/Btu.

[d] Coating system with granules.

Table 6. Summary of Selected Energy Factors Defined by Measured Areas

Table 7. Highest Roof Temperatures on System 2, Before and After Washing

Outside Temperature (°F)		Highest Roof Temperature (°F)		Date
Highest	Lowest	Before Washing	After Washing	
105	69	174	--	7-04-80
105	65	--	117	8-26-80
103	74	159	--	6-25-80
103	62	167	--	6-23-80
102	67	170	--	6-24-80
101	72	--	118	9-02-80
101	72	--	116	8-28-80
90	67	147	--	6-26-80
88	54	--	108	9-11-80

Table 8. Heating Monthly Degree-Days for the Clifton, N.J. Area[a]

Month	Heating Monthly Degree-Days									
	Before Foam Installation		After Foam Installation							
	1971-1972	1972-1973	1973-1974	1974-1975	1975-1976	1976-1977	1977-1978	1978-1979	1979-1980	1980-1981
Oct	95	356	166	341	195	381	319	239	289	314
Nov	569	599	479	521	400	745	527	481	393	654
Dec	724	776	787	802	913	1,107	975	830	763	1,066
Jan	909	906	909	864	1,177	1,361	1,168	1,001	953	1,261
Feb	969	882	921	832	738	895	1,099	1,155	987	762
Mar	757	504	661	775	645	563	814	577	802	764
Apr	444	339	273	524	338	352	411	386	366	290
May	93	163	127	84	141	89	190	68	62	96
Jun	19	1	12	6	17	24	13	11	24	0
Jul	0	0	0	0	0	0	6	2	0	0
Aug	0	0	0	1	4	0	0	4	0	
Sep	22	18	62	59	56	50	66	28	28	
Total	4,601	4,544	4,397	4,809	4,624	5,567	5,588	4,782	4,667	≥5,207
Avg.	4,572		4,603		5,096		5,185		4,937	

[a]Weather data obtained from monthly National Oceanic and Atmospheric Administration publication, "Climatological Data." for Newark, N. J.

Table 9. Monthly Gas Consumption

Month	Monthly Gas Consumption (cu ft)									
	Before Foam Installation		After Foam Installation							
	1971-1972	1972-1973	1973-1974	1974-1975	1975-1976	1976-1977	1977-1978	1978-1979	1979-1980	1980-1981
Oct	298,200	348,200	39,200	85,000	25,000	25,000	7,500	46,700	92,700	46,000
Nov	622,200	588,000	201,000	238,600	220,800	220,800	213,500	191,400	158,500	229,600
Dec	601,200	744,400	297,600	313,600	398,200	381,900	357,500	348,400	292,500	418,900
Jan	612,400	553,000	317,000	408,000	422,800	649,200	454,600	290,200	356,200	364,700
Feb	708,600	692,800	380,400	402,400	299,000	382,200	488,000	614,800	411,700	276,400
Mar	598,200	445,000	296,200	294,600	270,800	192,200	217,700	236,800	179,400	189,400
Apr	380,000	232,200	84,000	172,200	44,400	79,800	69,100	67,900	62,600	42,400
May	110,600	91,600	21,800	16,000	5,200	11,700	5,200	14,000	11,600	10,700
Jun	24,200	7,200	6,800	3,600	5,000	11,700	2,600	2,900	11,600	4,100
Jul	7,000	6,400	6,000	3,600	5,000	1,800	5,300	2,900	3,900	3,300
Aug	6,200	5,400	7,800	4,200	5,000	4,000	3,000	3,700	3,700	3,200
Sep	47,600	7,400	7,200	4,600	4,400	5,000	3,900	3,800	3,800	3,300
Monthly Avg. Oct-May	491,425	460,775	204,650	241,300	210,775	242,850	226,638	226,275	195,650	197,238
Avg.	476,100									
Reduction Gas Usage[a]			57%	49%	56%	49%	52%	52%	59%	59%
Heating Monthly Degree Days		4,572	4,397	4,809	4,624	5,567	5,588	4,782	4,667	5,207

[a]Referred to the average monthly gas usage of 476,100 cu ft prior to foaming. Average reduction/year = 54%.

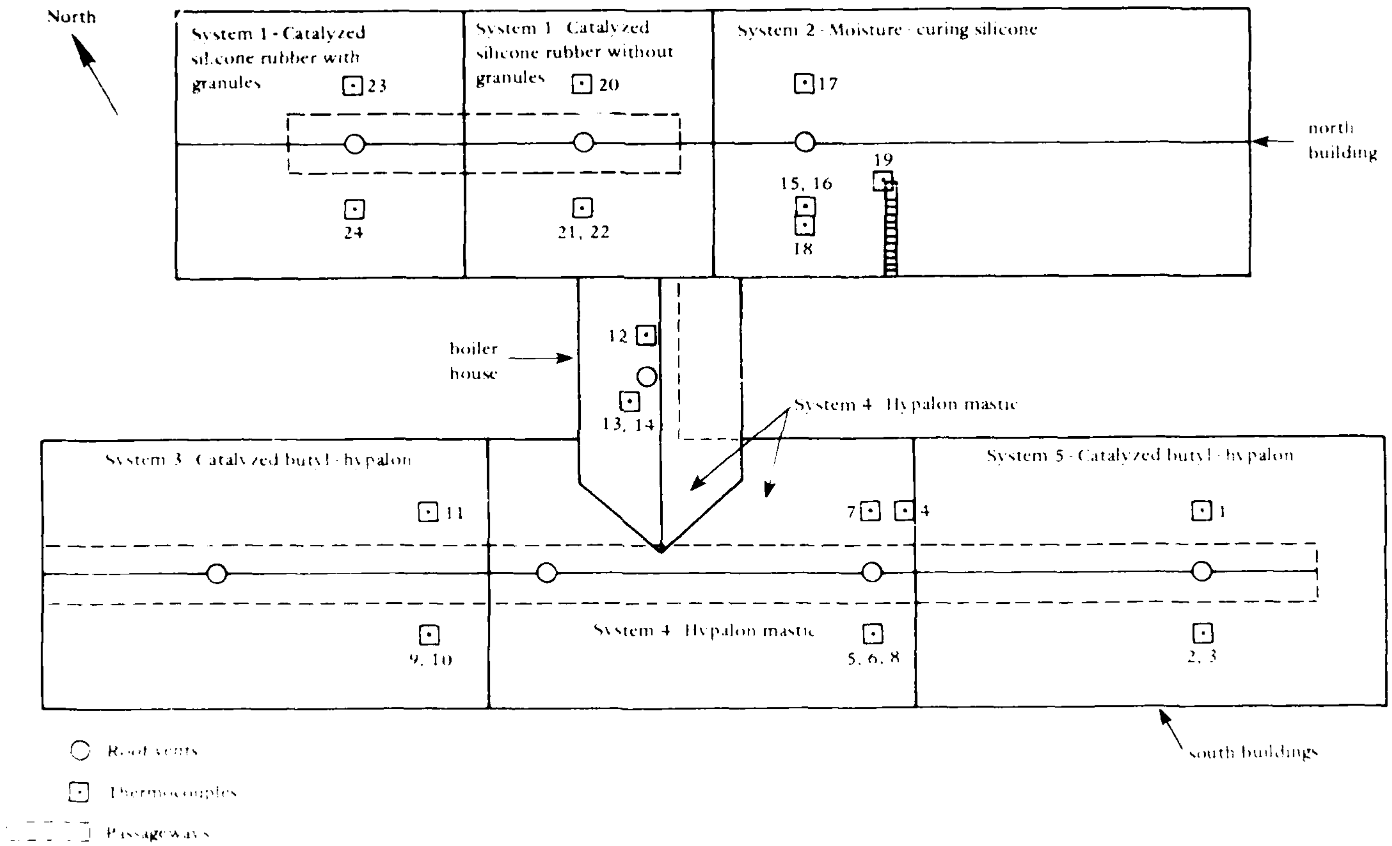
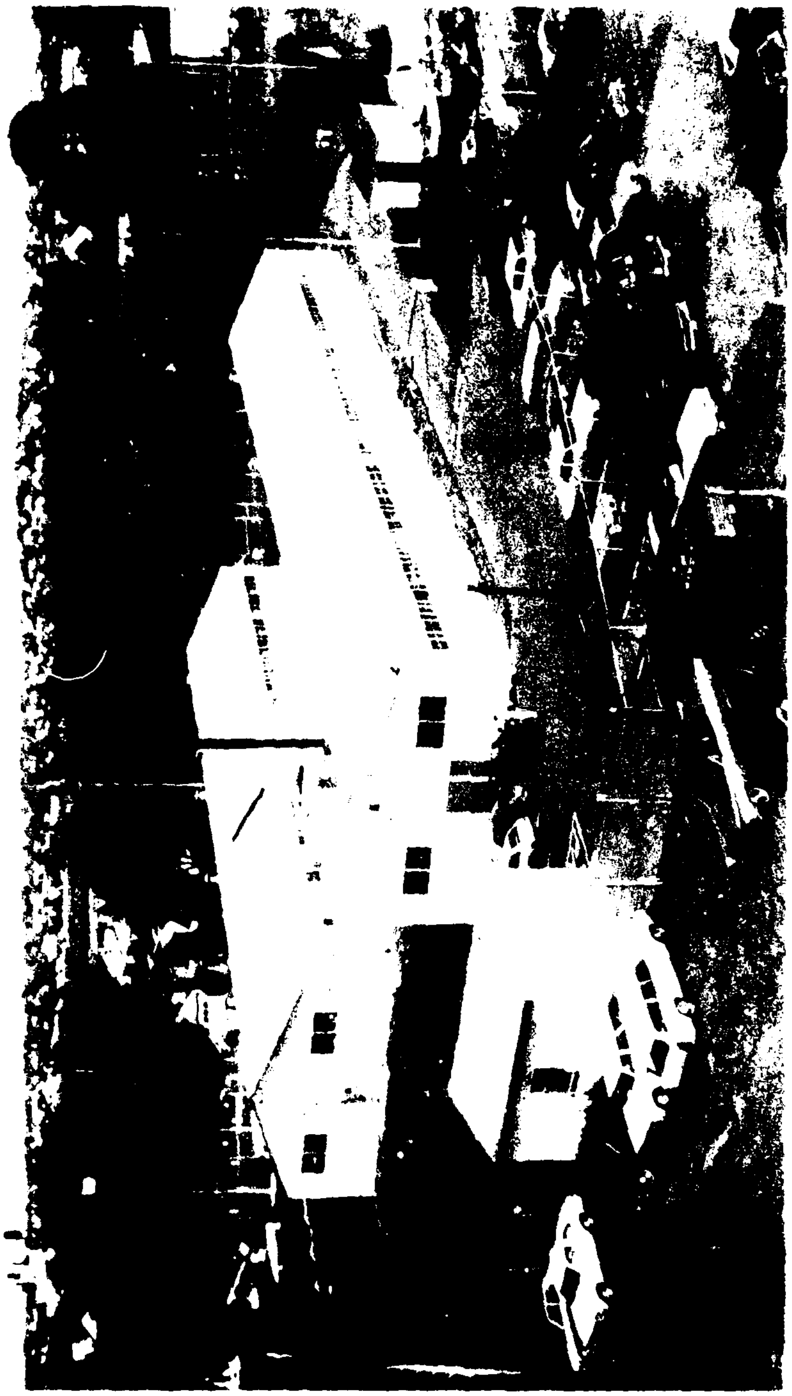


Figure 1. Location of thermocouples and coating systems on Reserve Center buildings.



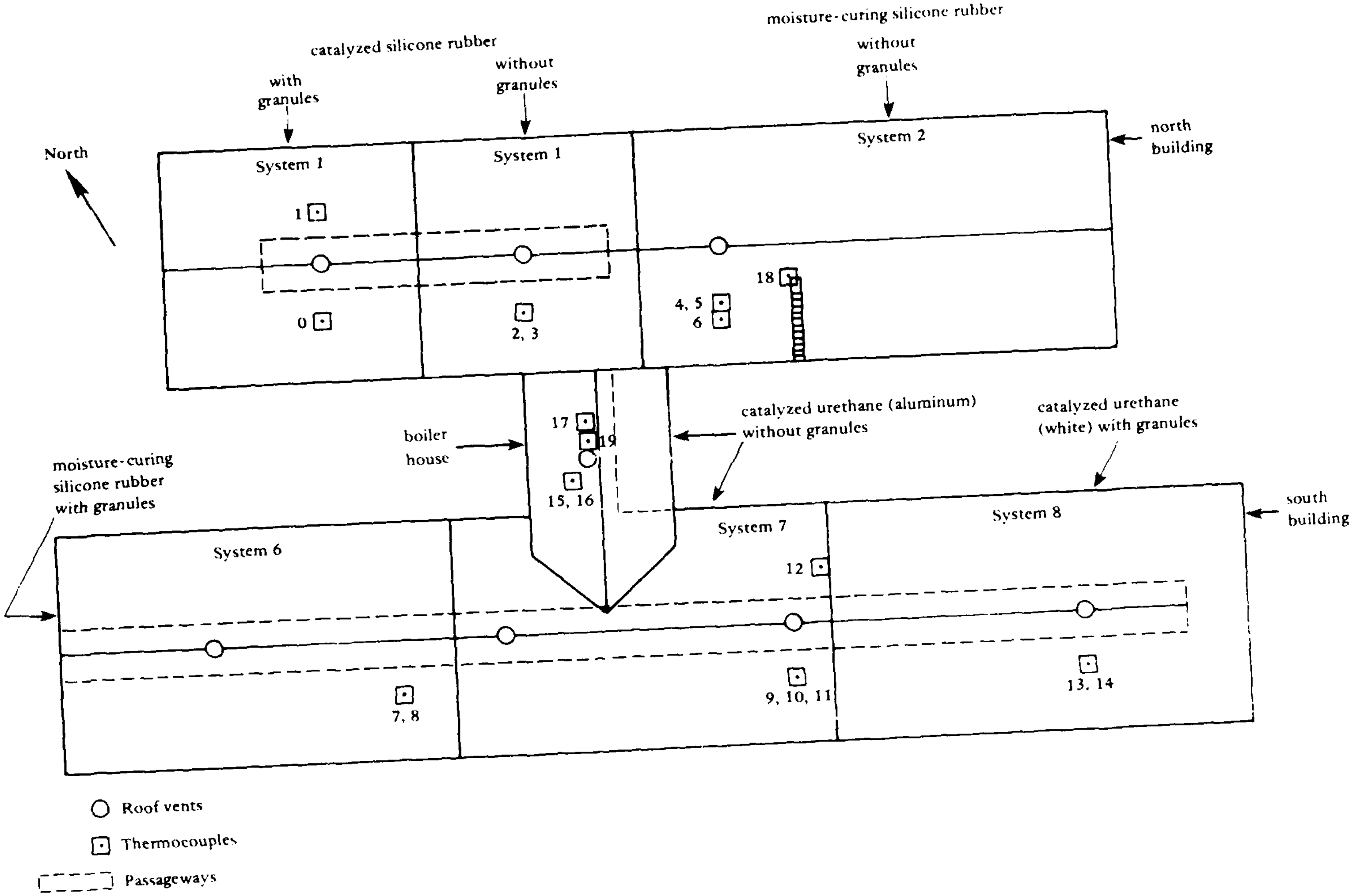


Figure 3. Current layout of thermocouples and coating systems on Reserve Center buildings

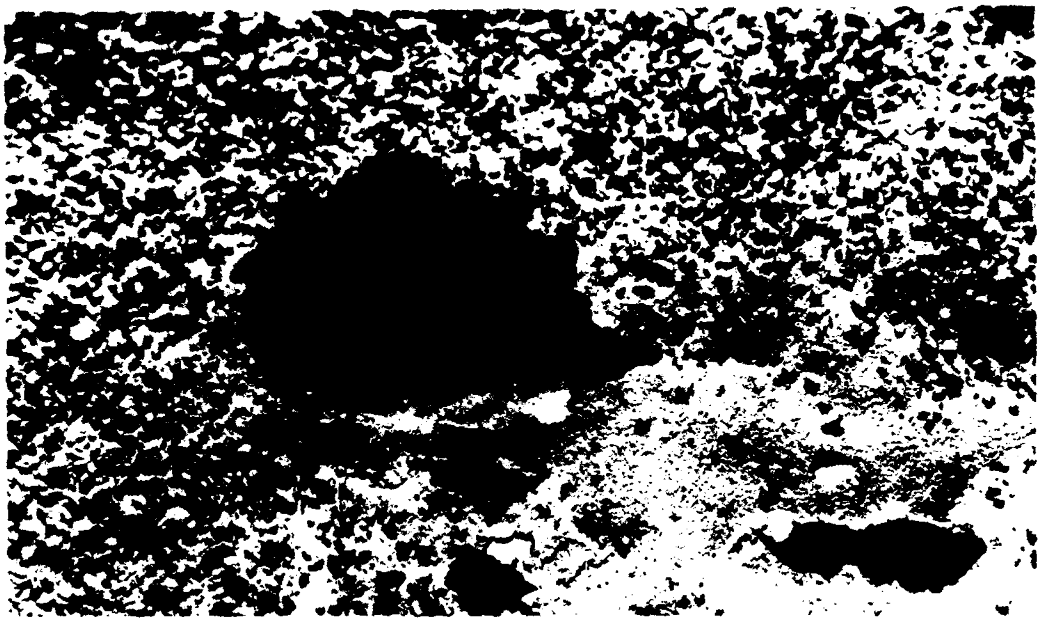
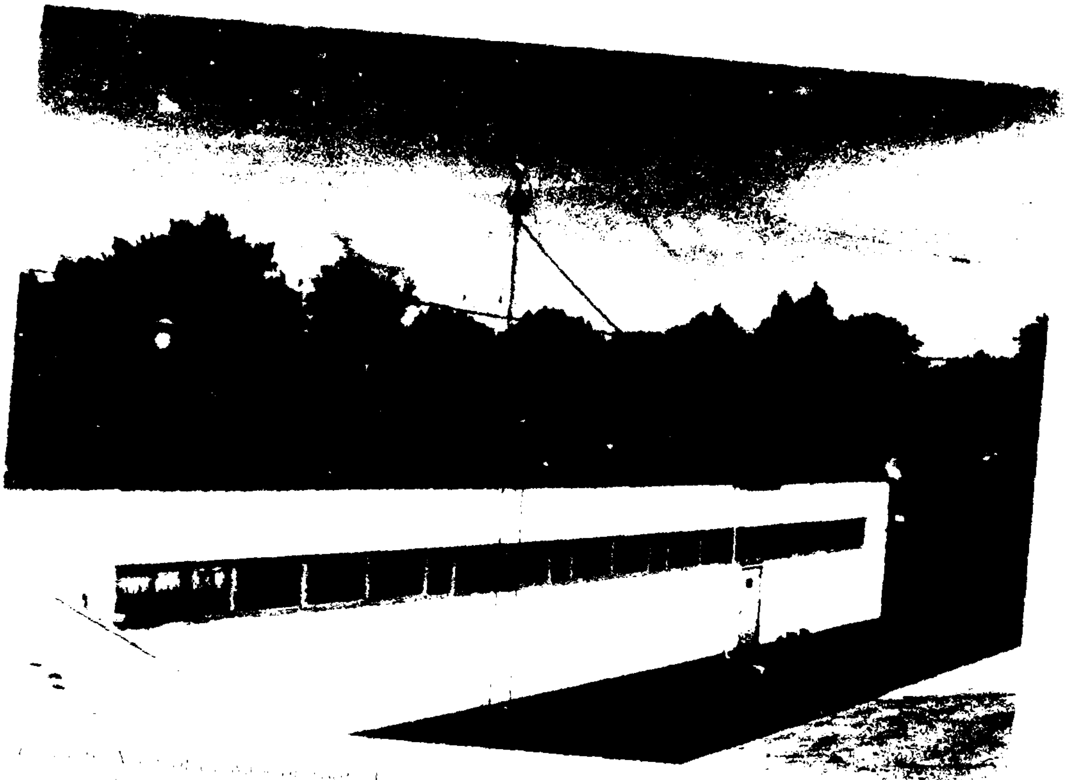


Figure 4. Small isolated bird pecks through coating in foam are easily repaired with a calking gun.

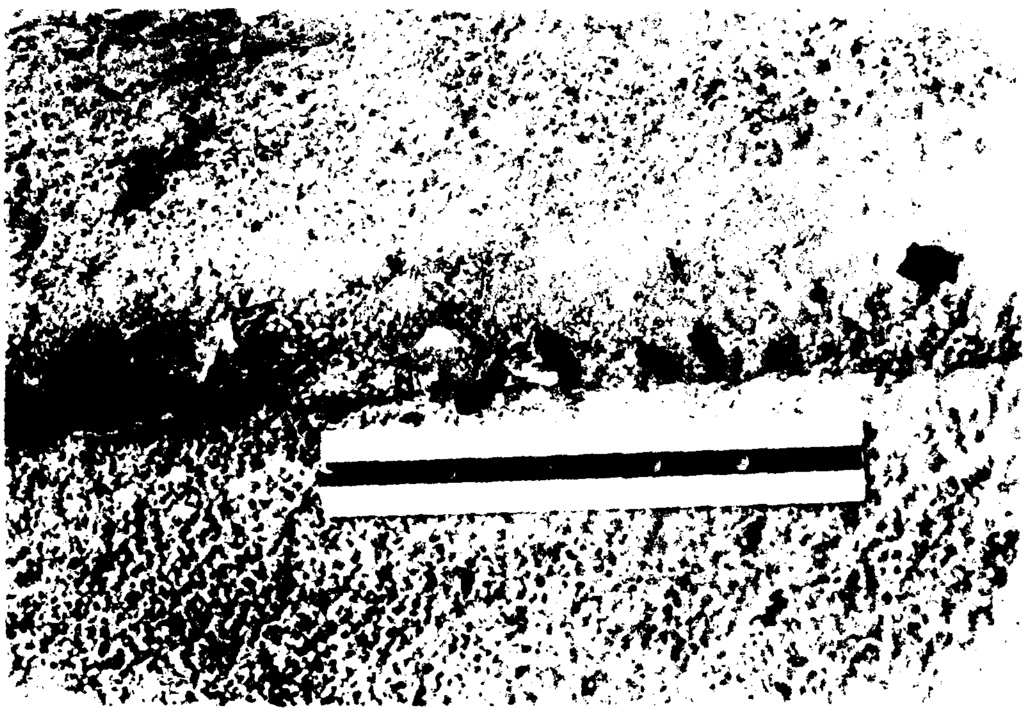
Figure 5. Overview of southerly surface of System I. After seven years, System I was performing very well and was rated very good.



[illegible] heavy damage to coating and foam.

Figure 7. System 2 coating peeling in small areas, 1 to 3 in. because of damage to underlying surface foam.

Figure 8. Small birds entering underneath gravel stop pecked out foam and nested.



[illegible] occurred along top of ribs where foam damage [illegible]
[illegible] load

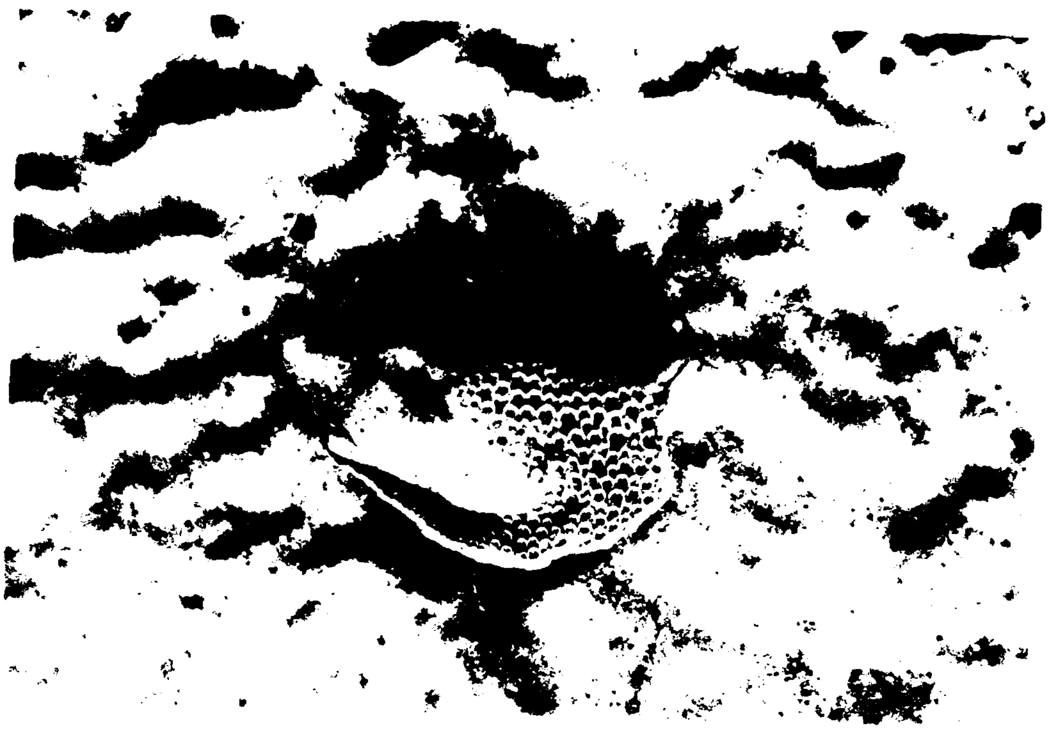


Figure 10. Small area of wet foam in System 2. Water exudes when foam is pressed.

Figure 11. Cracking of silicone coating of System 2 along base of rib. Spraying foam and coating in two directions ("cross hatched") rather than in only one direction would have eliminated the problem.

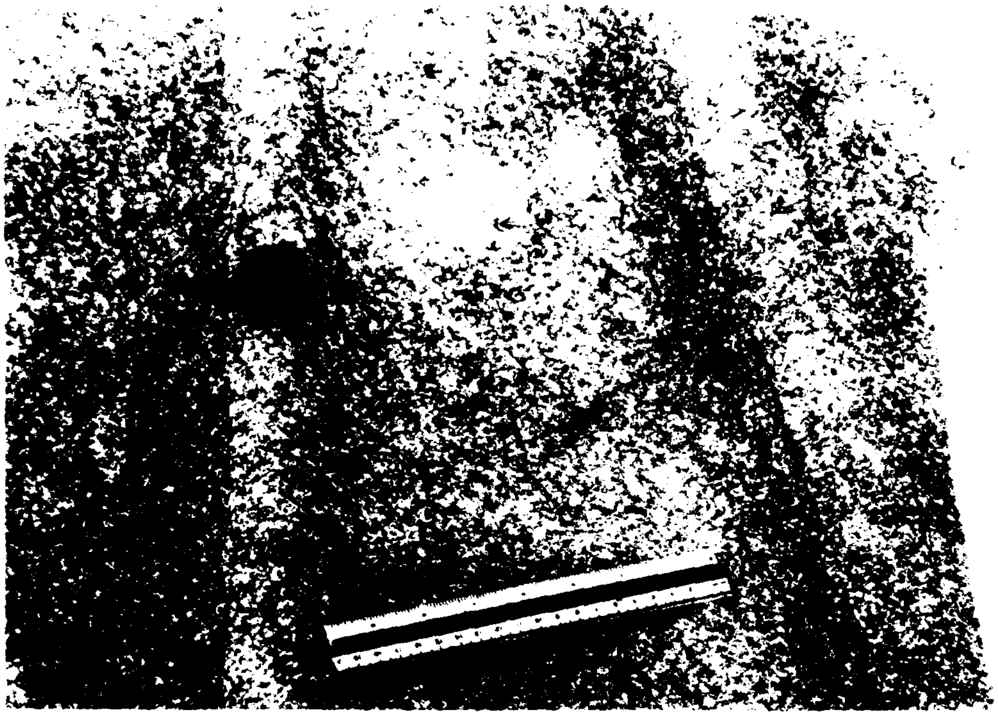


Figure 12. Hailstone cracks in original coating system caused during hailstorm have mirrored through silicone coating of System 6 leading to deterioration of foam around cracks.

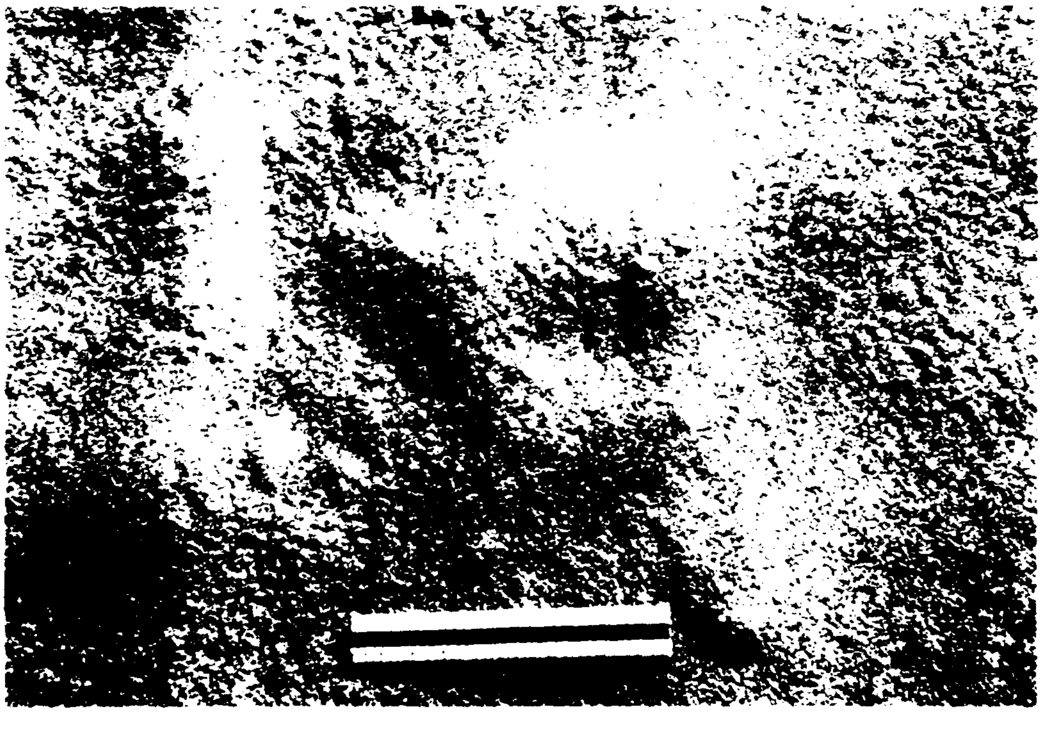


Figure 13. Small area of foam delamination (top lift blistered from bottom lifts), approximately 1 to 1½ ft^2 (System 6). Roof system is still waterproof and dry.

Figure 14 Blisters in System 7 coating attributed to moisture on System 4 when recoated with System 7

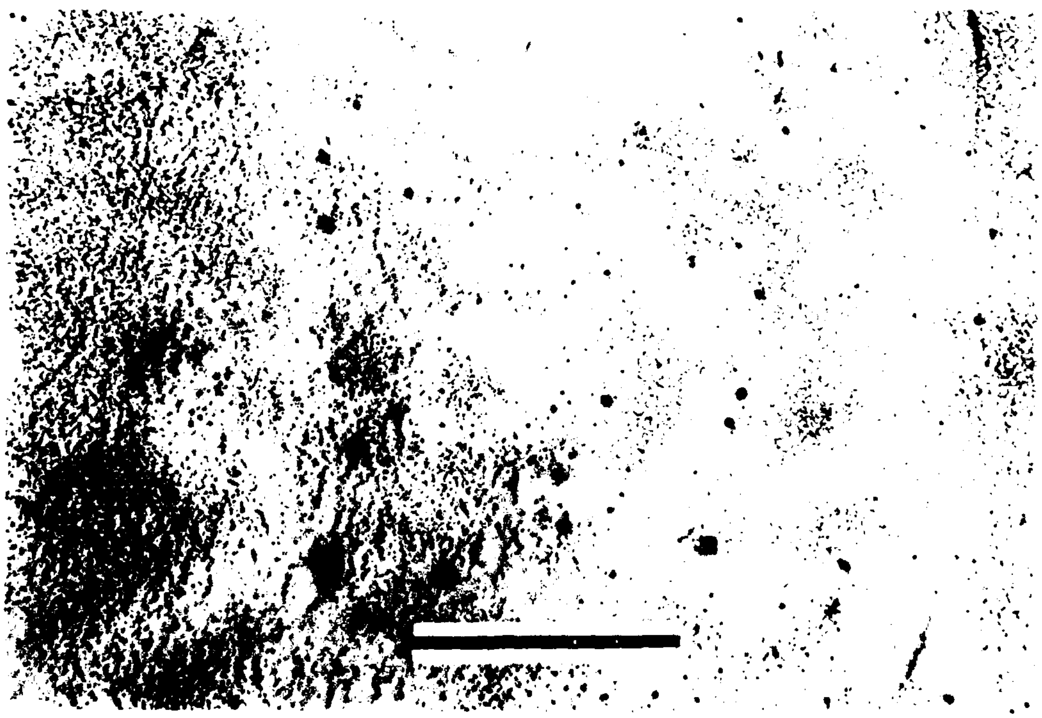


Figure 15 Black pinholes in coating of System 7 appear to indicate presence of moisture on PCI. Figure also illustrates severe orange peel effect with topcoat of this system

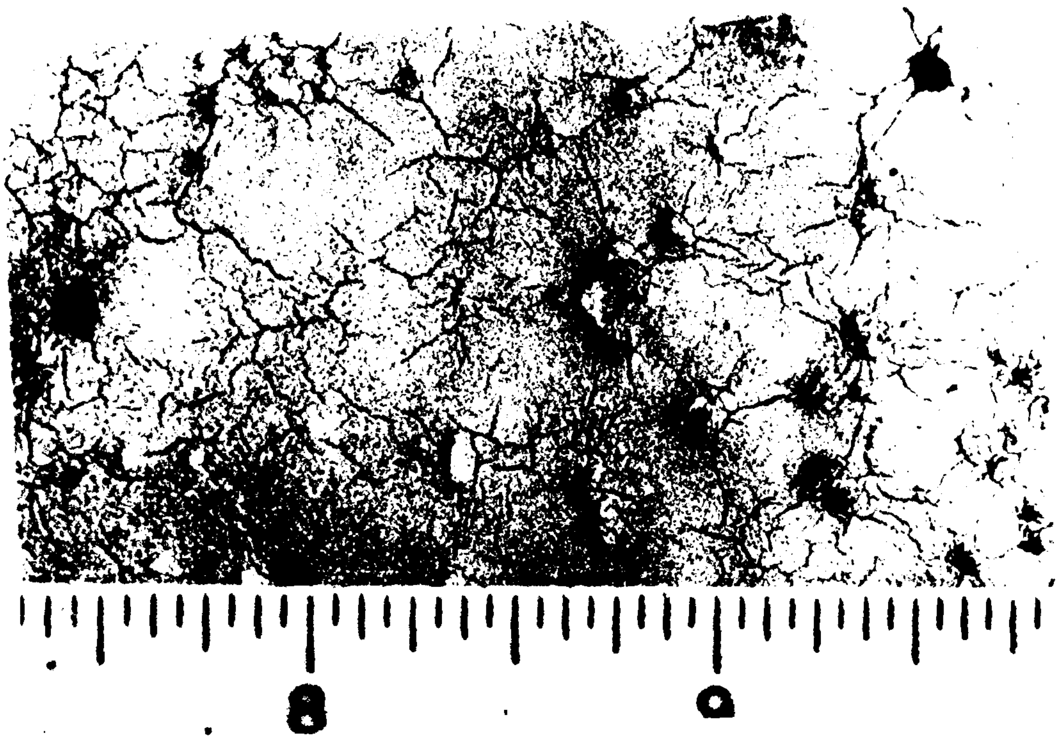


Figure 16 Crazing and checking of aluminum topcoat of System 7

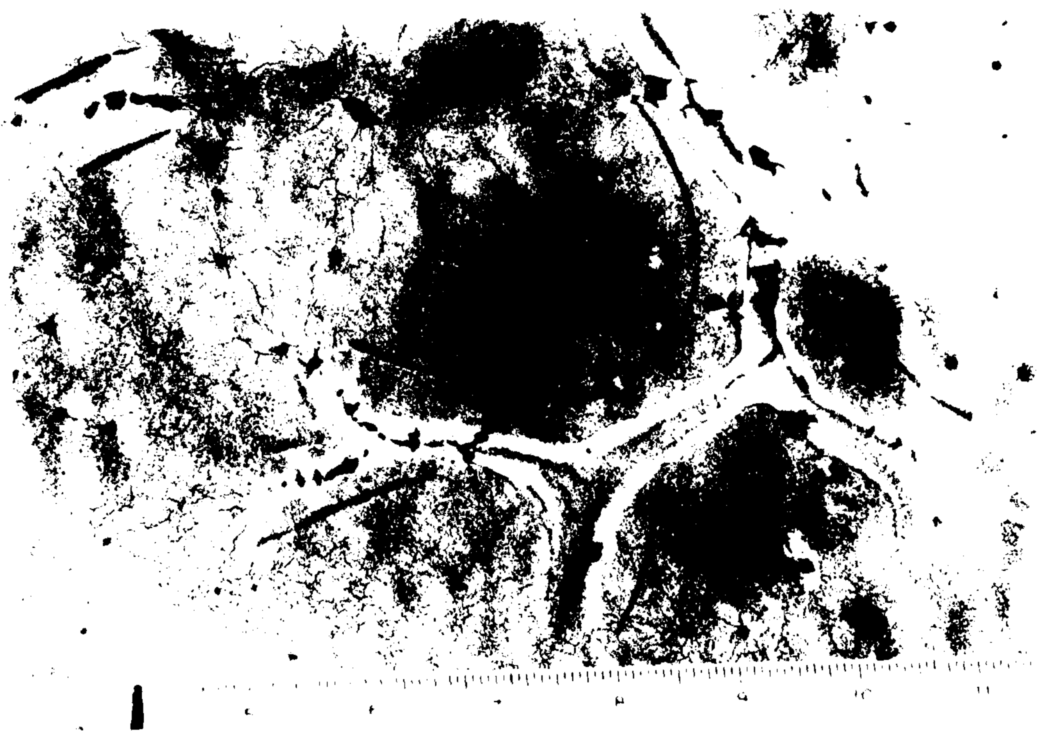


Figure 17 Unusual blistering pattern and resultant flaking of aluminum topcoat of System 7

Figure 18. Aluminum topcoat of System 7 exhibited cracking [illegible] after six to seven years of weathering.

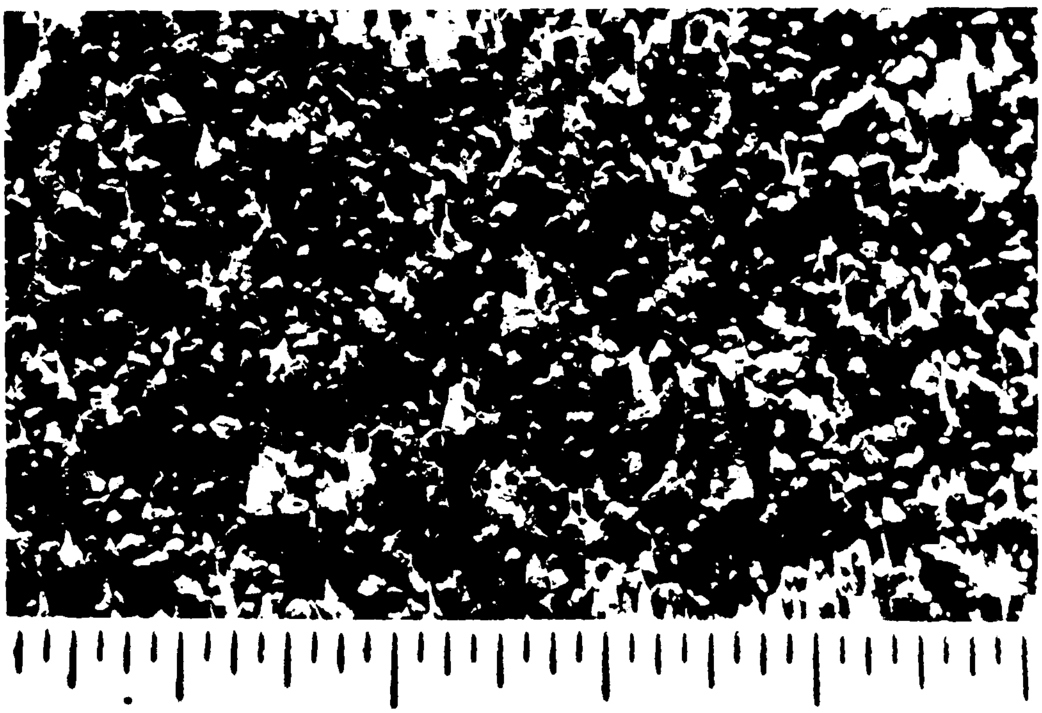


Figure 19. Cracks in original coating system caused by hailstones have mirrored through urethane coating of System 8 but has caused no noticeable foam deterioration underneath the cracks.

Figure 20. Overview of System 8 showing very good performance of this urethane elastomer system in spite of hailstone cracks mirrored through recoat system.

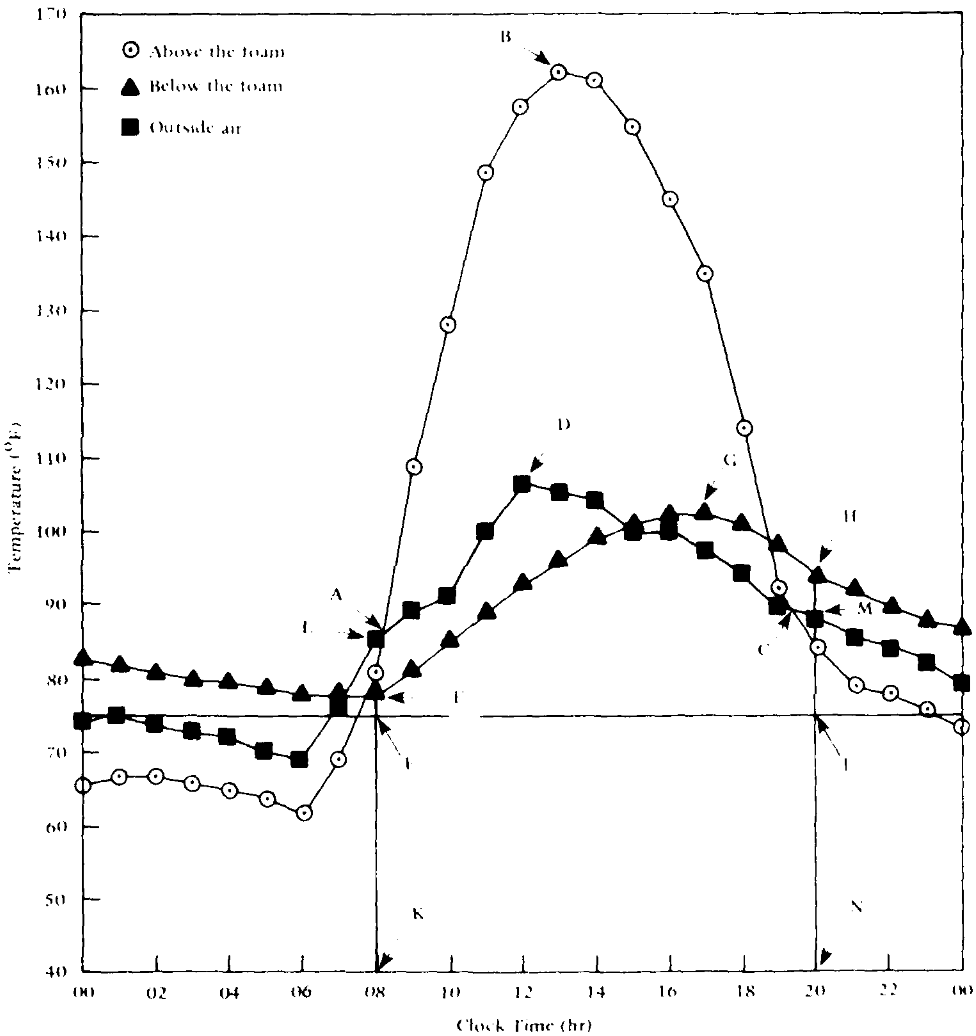


Figure 21. Temperatures in moisture curing silicone section with granules (System 6) for July 13, 1979.

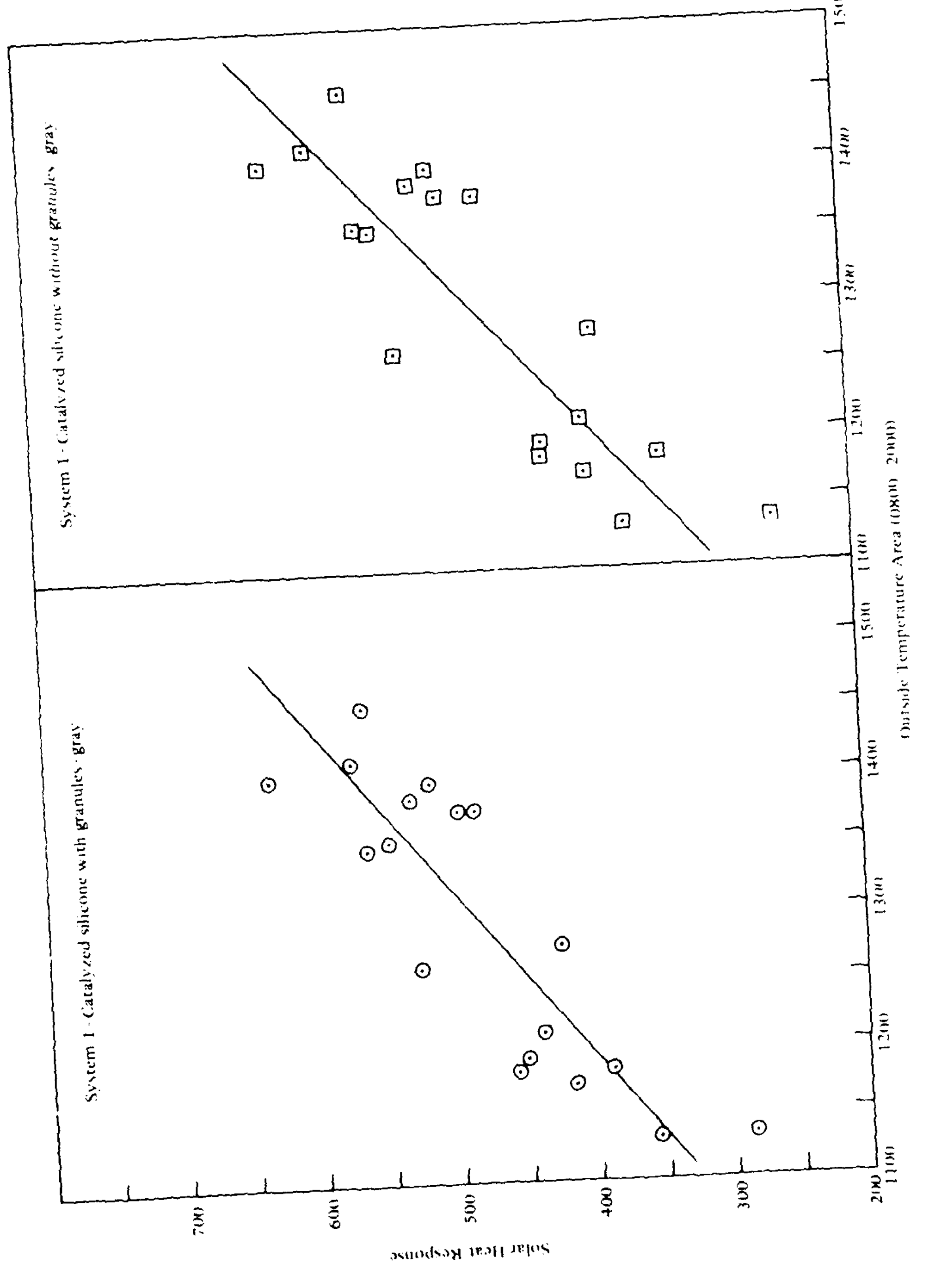


Figure 22. Solar heat response on catalyzed silicone roof sections.

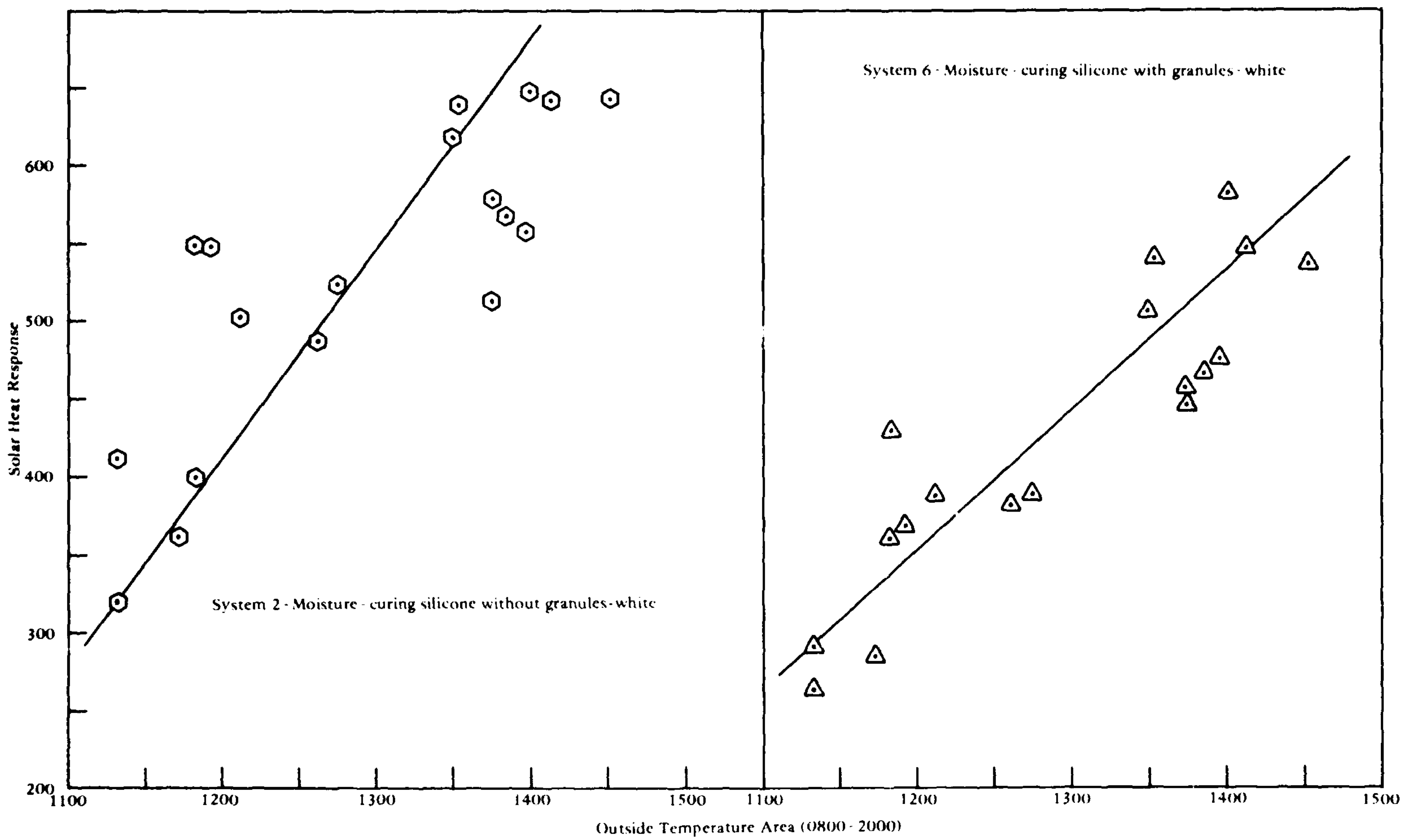


Figure 23. Solar heat response on moisture - curing silicone roof sections.

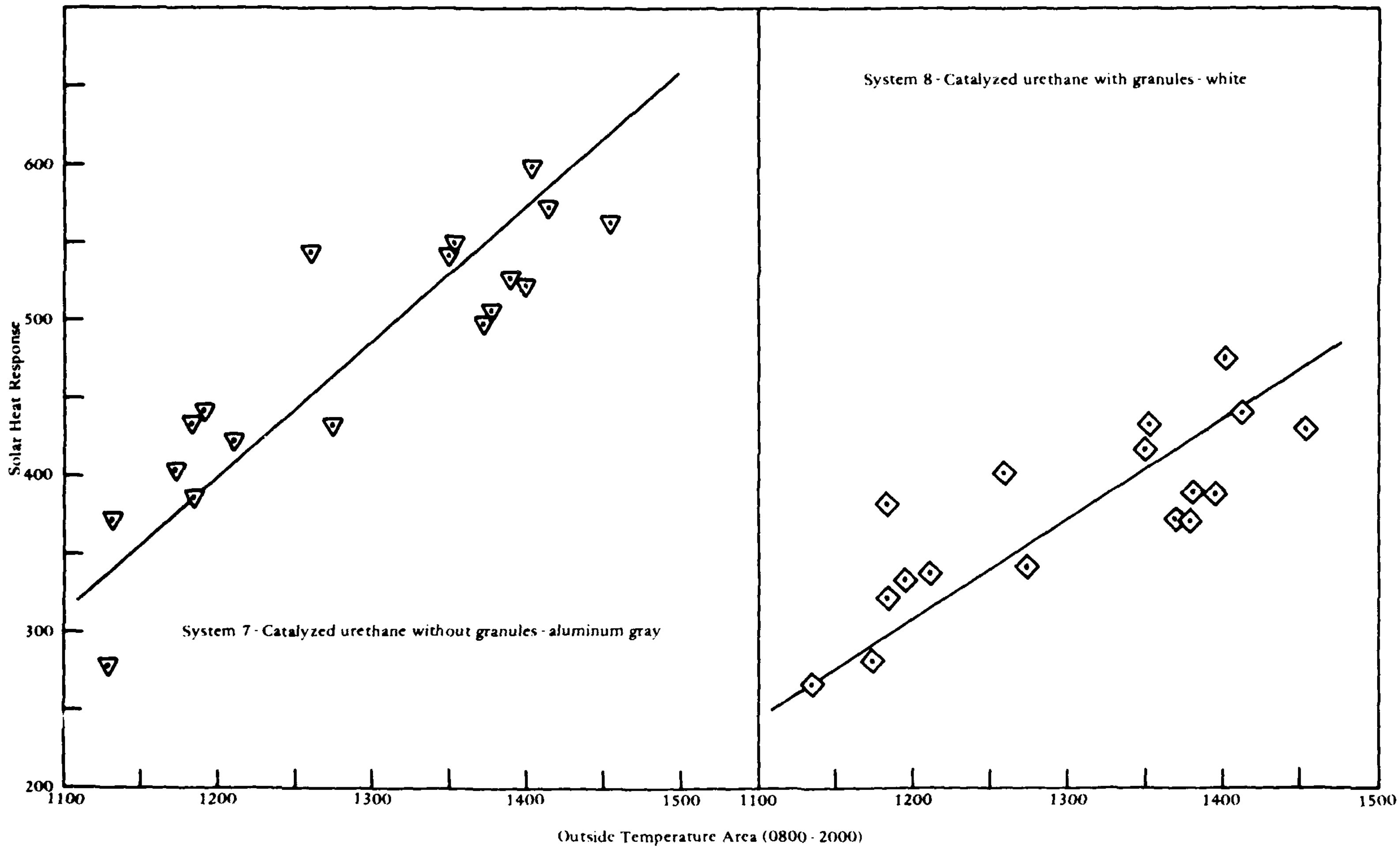


Figure 24. Solar heat response on catalyzed urethane roof sections.

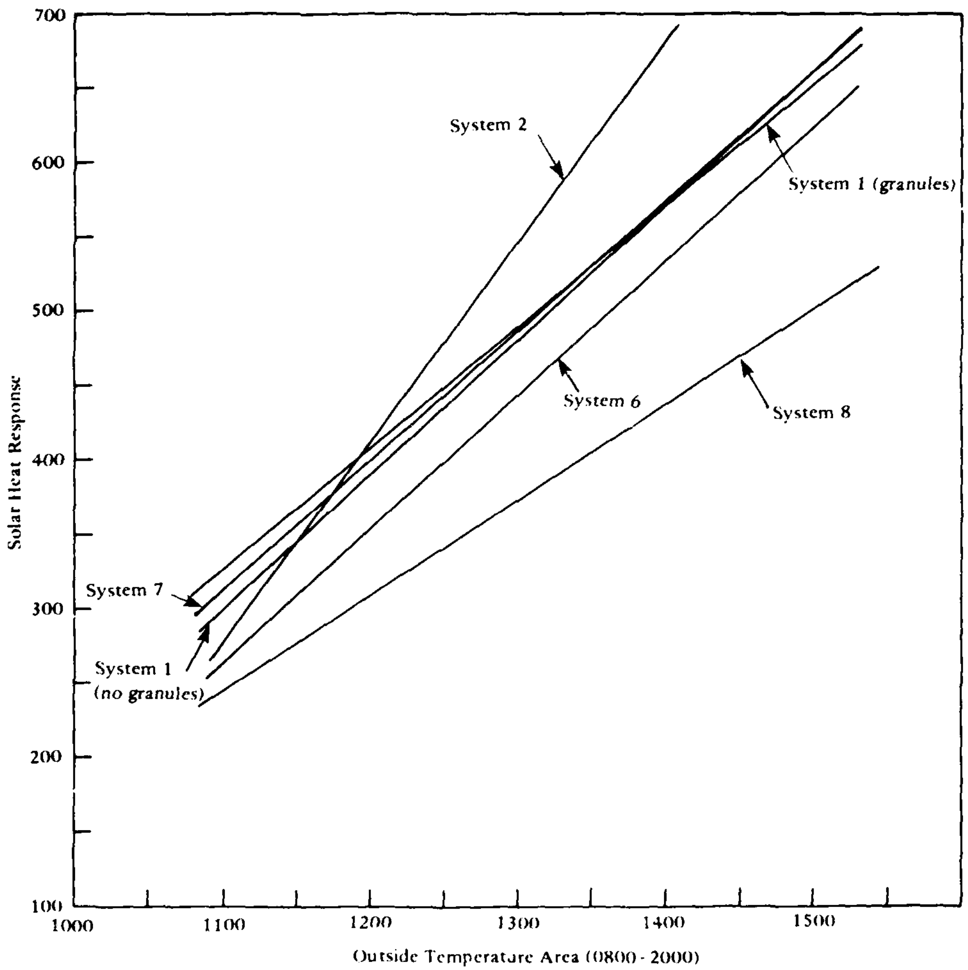


Figure 25. Solar heat response on all roofs, summers of 1978, 1979, 1980.

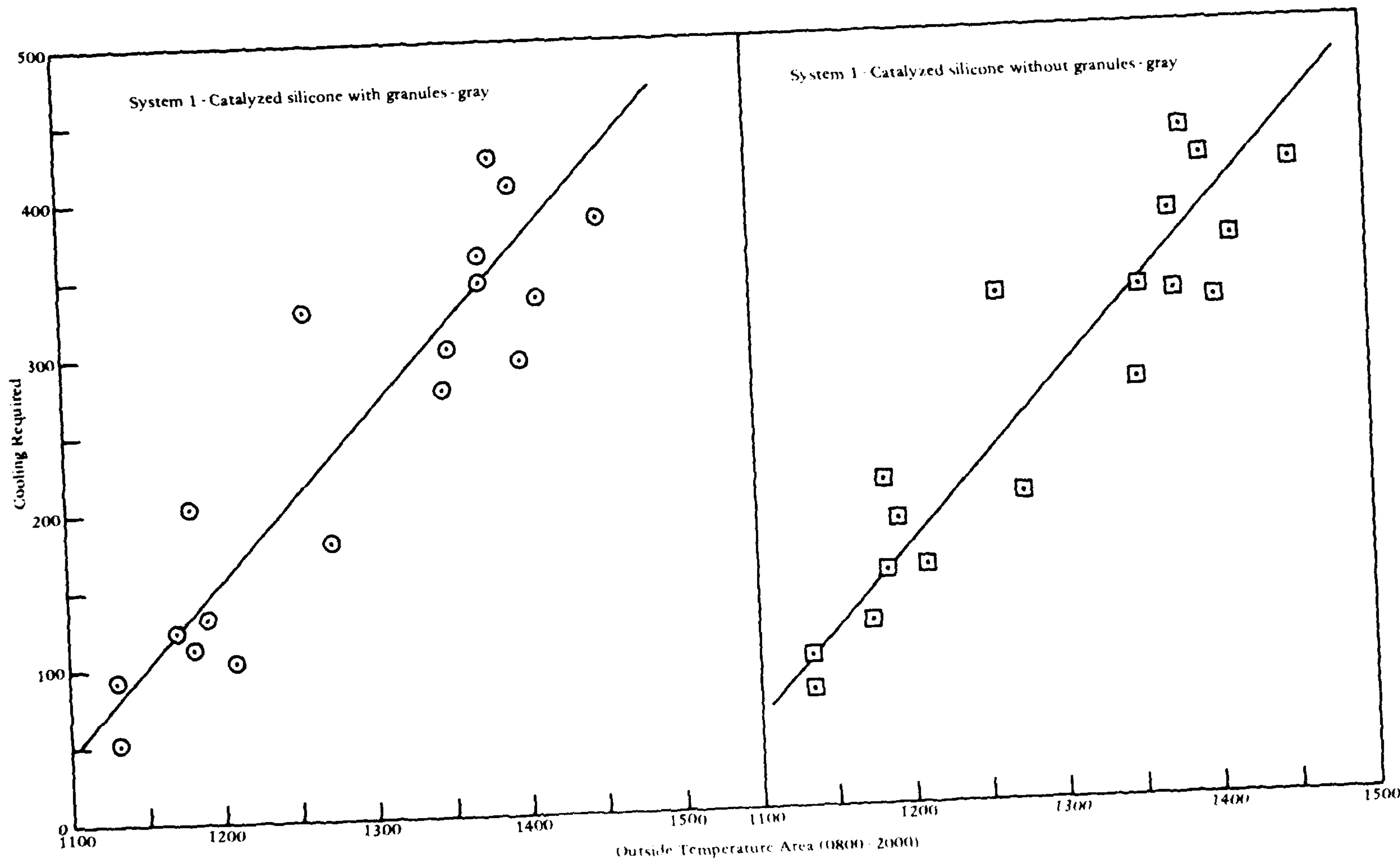


Figure 26. Cooling required on catalyzed silicone roof sections

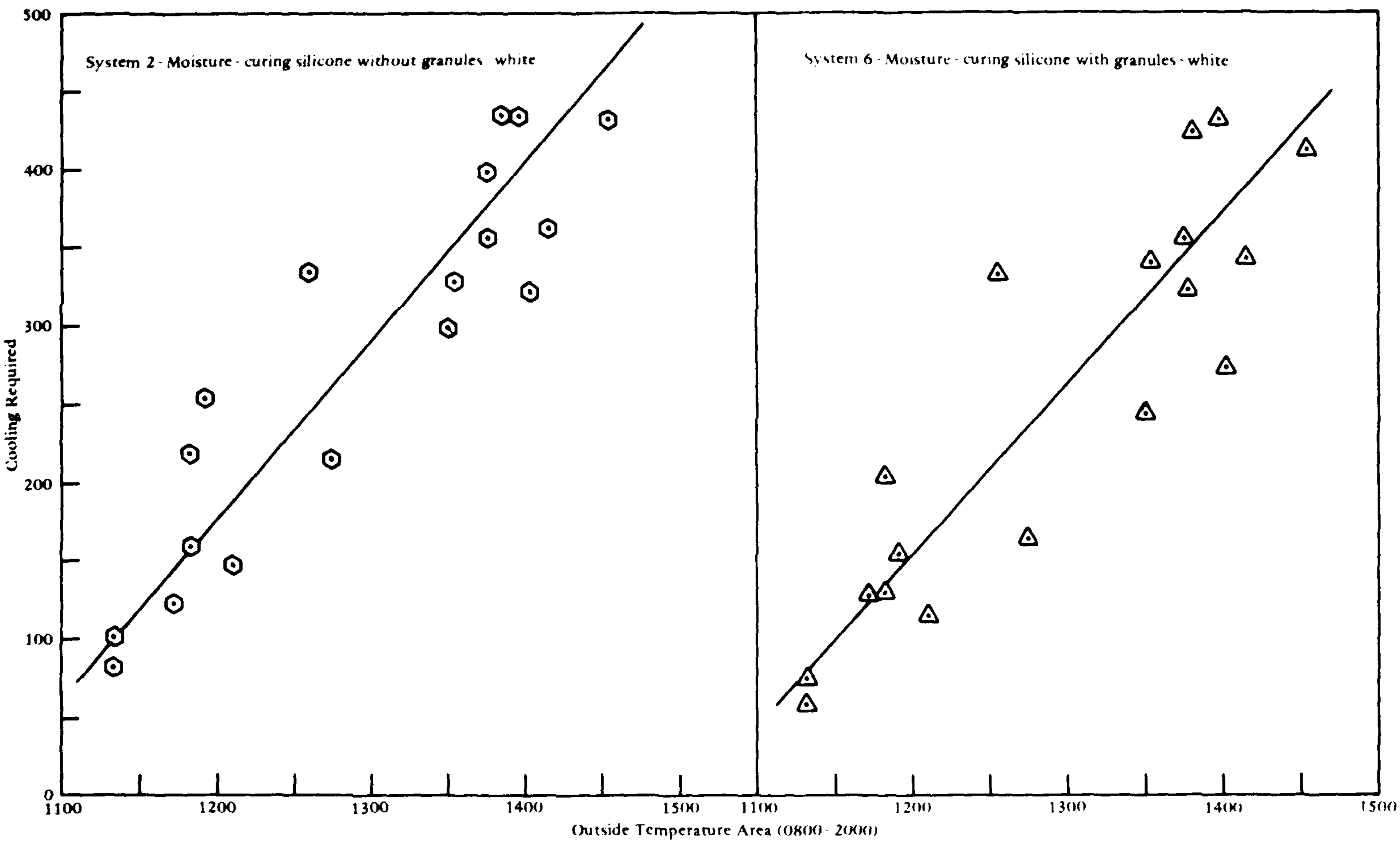


Figure 27. Cooling required on moisture curing silicone roof sections.

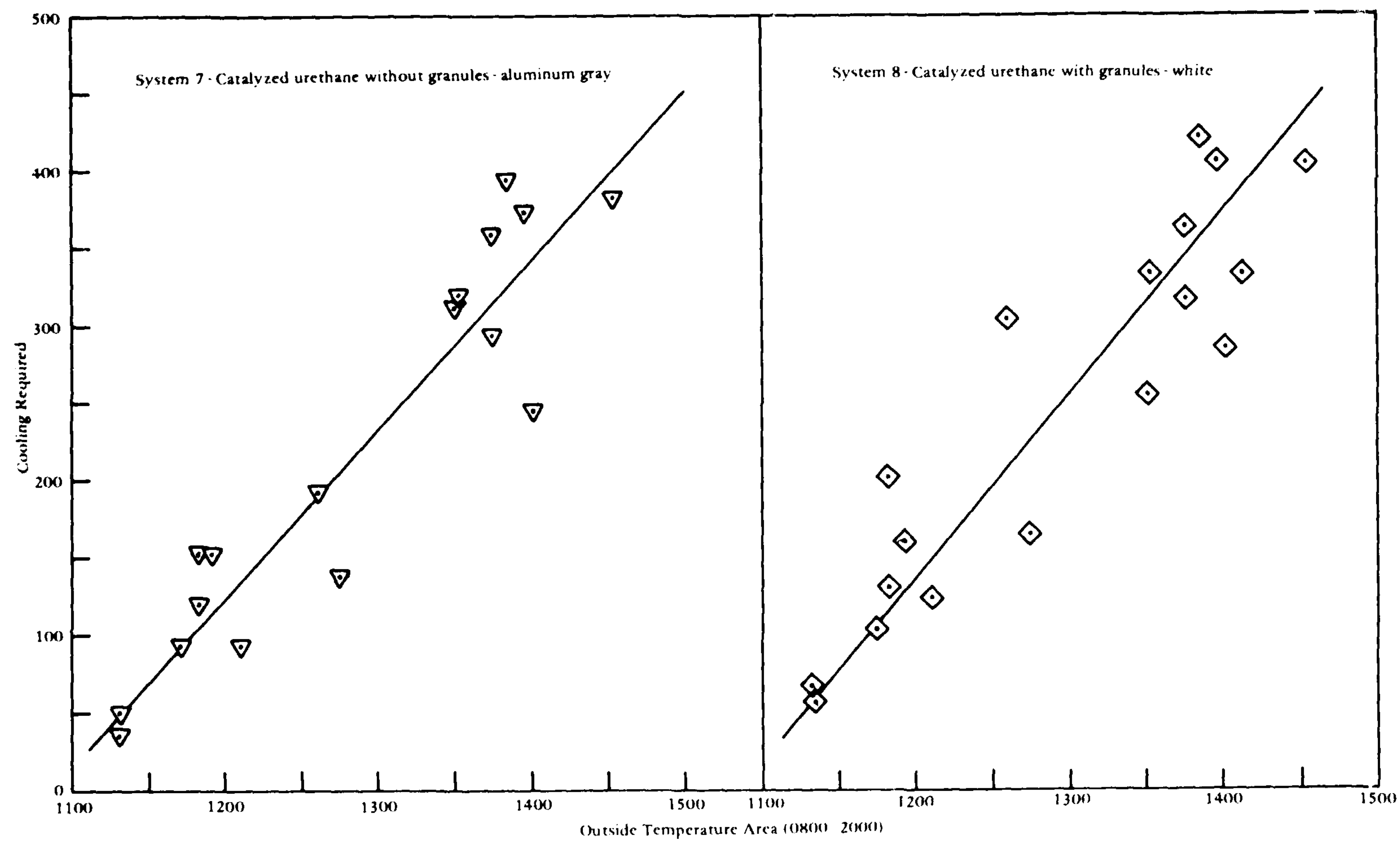


Figure 28. Cooling required on catalyzed urethane roof sections.

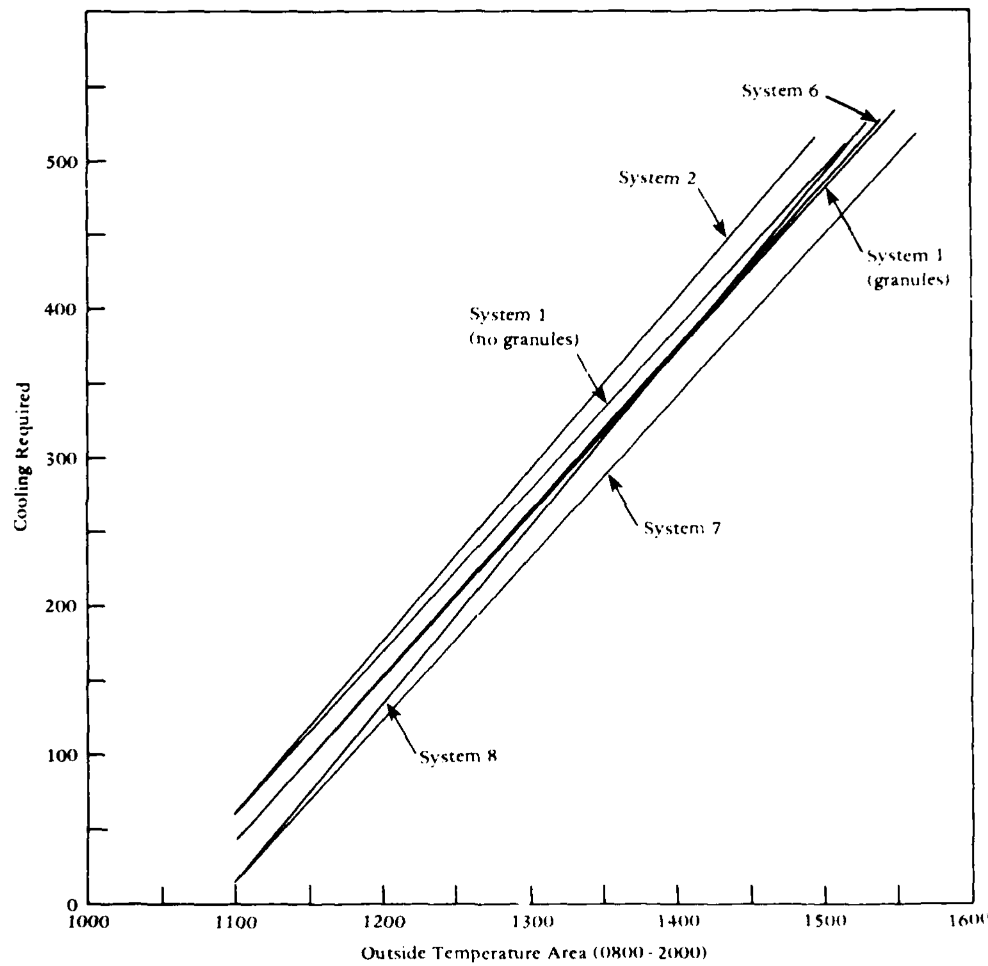


Figure 29. Cooling required on all roofs, summers of 1978, 1979, 1980.

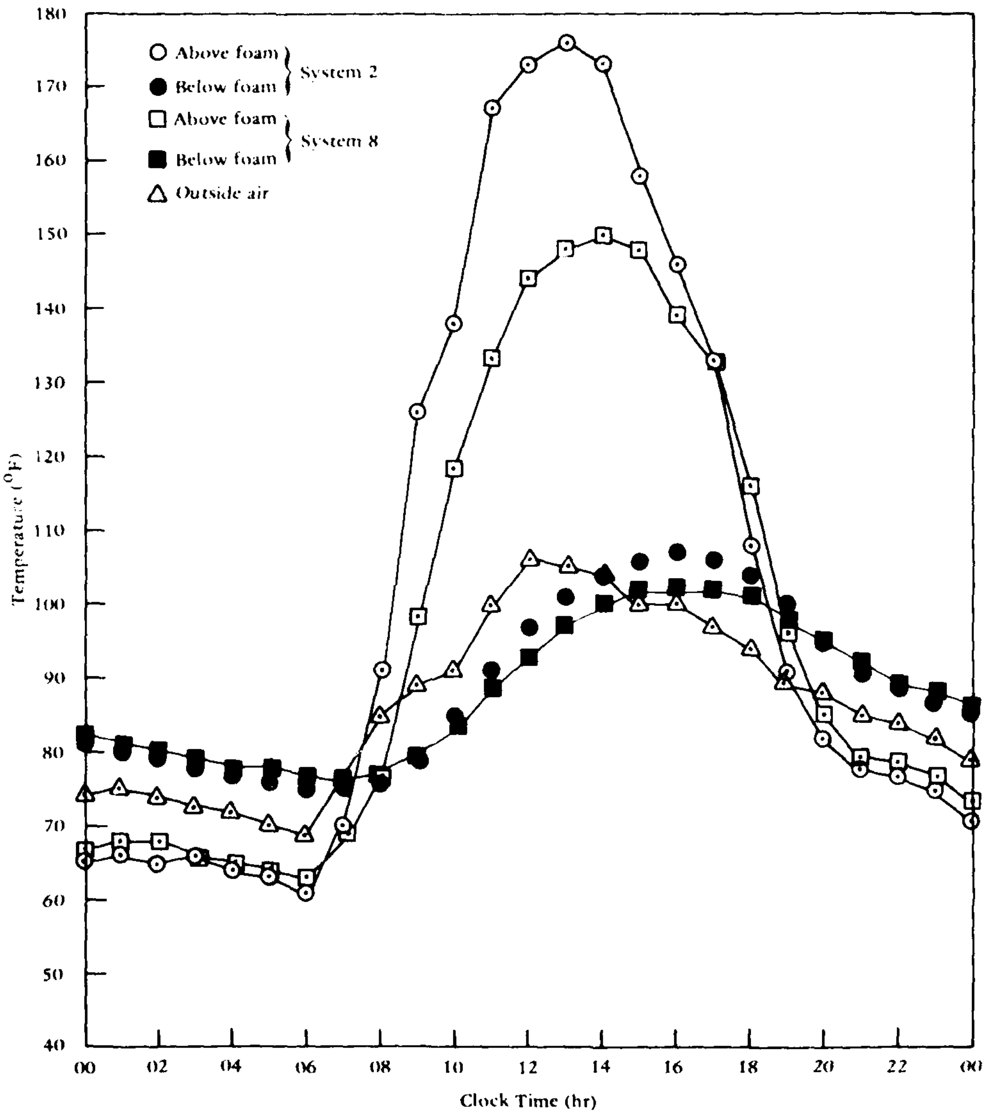


Figure 30. Temperatures in Systems 2 and 8 for July 13, 1979.

Appendix

MANUFACTURERS AND TRADE NAMES OF MATERIALS USED IN EXPERIMENTAL ROOFS

Item	Material	Source
Urethane Foam	CPR-485 Components A & B	CPR Division, The Upjohn Company 555 Alaska Avenue Torrance, CA 90503
System 1.	Silicone Weather Coatings SCM 3308/501C SCM 3304/3007C Granusils SCM 3551	Silicone Products Department General Electric Company Waterford, NY 12188
System 2.	3-5000 Construction Coating	Dow Corning Corporation Midland, MI 48640
System 3.	PC 8105 PC8204	U. S. Polymeric 700 East Dyer Road Santa Ana, CA 92707
System 4.	Monolar Mastic No. 60-36	Foster Division Amchem Products, Inc. Ambler, PA 19002
System 5.	Elastron Number 858 Elastomir Hypalon #35	United Coatings 1130 E. Sprague Spokane, WA 99202
System 6.	3-5000 Construction Coating Mineral Roofing Granules	Dow Corning Corporation Midland, MI 48640
System 7.	Roof-Flex 145 Roof-Flex 155A	Carboline Corporation St. Louis, MO
System 8.	Irathane W00-8 Primer 300 Basecoat 394 Topcoat	Irathane Hibbing, MN

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CINCPAC Fac Engrng Div (J44) Makalapa, HI
CNAVRES Code 13 (Dir. Facilities) New Orleans, LA
CNM Code MAT-04, Washington, DC; Code MAT-08E, Washington, DC; NMAT - 044, Washington DC
CNO Code NOP-964, Washington DC; Code OP 987 Washington DC; Code OP-413 Wash, DC; Code OPNAV 09B24 (H); OP-098, Washington, DC; OP987J, Washington, DC
COMCBPAC Operations Off, Makalapa HI
COMFLEACT, OKINAWA PWD - Engr Div, Sasebo, Japan; PWO, Kadena, Okinawa; PWO, Sasebo, Japan
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COMNAVMARIANAS Code N4, Guam
COMOCEANSYSLANT PW-FAC MGMNT Off Norfolk, VA
COMOCEANSYSPAC SCE, *Pearl Harbor HI*
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DOE Div Ocean Energy Sys Cons/Solar Energy Wash DC; F.F. Parry, Washington DC; INEL Tech. Lib. (Reports Section), Idaho Falls, ID
DTIC Defense Technical Info Ctr/Alexandria, VA
DTNSRDC Anna Lab, Code 4121 (R A Rivers) Annapolis, MD
DTNSRDC Code 172 (M. Krenzke), Bethesda MD
DTNSRDC Code 284 (A. Rufolo), Annapolis MD
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MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code S4, Quantico VA; Facs Maint Dept - Operations Div, Cherry Point; PWD - Utilities Div, Iwakuni, Japan; PWD, Dir. Maint. Control Div., Iwakuni Japan; PWO, Iwakuni, Japan; PWO, Yuma AZ

MCDEC M&L Div Quantico VA; NSAP REP, Quantico VA

MCLB B520, Barstow CA; Maintenance Officer, Barstow, CA; PWO, Barstow CA

MCRD SCE, San Diego CA

NAF PWD - Engr Div, Atsugi, Japan; PWO, Atsugi Japan

NALF OINC, San Diego, CA

NARF Code 100, Cherry Point, NC; Code 612, Jax, FL; Code 640, Pensacola FL; Equipment Engineering Division (Code 61000), Pensacola, FL; SCE Norfolk, VA

NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 6234 (G. Trask), Point Mugu CA; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX; Dir. Maint. Control Div., Key West FL; Dir. Util. Div., Bermuda; Grover, PWD, Patuxent River, MD; Lakehurst, NJ; Lead. Chief. Petty Offr. PW Self Help Div, Beeville TX; OIC, CBU 417, Oak Harbor WA; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Gtmo, Cuba; PWD - Engr Div, Oak Harbor, WA; PWD Maint. Cont. Dir., Fallon NV; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWD, Maintenance Control Dir., Bermuda; PWD, Willow Grove PA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO Lakehurst, NJ; PWO Sigonella Sicily; PWO Whiting Fld, Milton FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO., Moffett Field CA; SCE Norfolk, VA; SCE, Barbers Point HI; SCE, Cubi Point, R.P; Security Offr, Alameda CA

NASDC WDC L. Fry, Manassas VA

NATL BUREAU OF STANDARDS B-348 BR (Dr. Campbell), Washington DC

NATL RESEARCH COUNCIL Naval Studies Board, Washington DC

NAVACT PWO, London UK

NAVACTDET PWO, Holy Lock UK

NAVAEROSPREGMEDCEN SCE, Pensacola FL

NAVAIRDEVCEN Chmielewski, Warminster, PA; Code 813, Warminster PA; PWD, Engr Div Mgr, Warminster, PA

NAVAIRPROPTESTCEN CO, Trenton, NJ

NAVAVIONICFAC PW Div Indianapolis, IN; PWD Deputy Dir. D/701, Indianapolis, IN

NAVAVNWPNSFAC Wpns Offr, St. Mawgan, England

NAVCHAPGRU Engineering Officer, Code 60 Williamsburg, VA

NAVCOASTSYSCEN CO, Panama City FL; Code 423 Panama City, FL; Code 718 (J. Quirk) Panama City, FL; Code 715 (J. Mittleman) Panama City, FL; Library Panama City, FL; PWO Panama City, FL

NAVCOMMAREAMSTRSTA Code W-60, Elec Engr, Wahiawa, HI; PWO, Norfolk VA; SCE Unit 1 Naples Italy; SCE, Wahiawa HI

NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia; SCE, Balboa, CZ

NAVCONSTRACEN Curriculum/Instr. Stds Offr, Gulfport MS

NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL

NAVEDUTRACEN Engr Dept (Code 42) Newport, RI

NAVENVIRHLTHCEN CO, NAVSTA Norfolk, VA

NAVEODTECHCEN Code 605, Indian Head MD

NAVFAC PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Point Sur, Big Sur CA

NAVFACENGCOM Code 031 (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0453 (D. Potter) Alexandria, VA; Code 046; Code 0461D (V M Spaulding) Alexandria, VA; Code 04A1 Alexandria, VA; Code 04B3 Alexandria, VA; Code 081A Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 100 Alexandria, VA; Code 1002B (J. Leimanis) Alexandria, VA; Code 1113 Alexandria, VA; Code 111A Alexandria, VA; Code 461D, Alexandria, VA; code 081 Alexandria, VA; Code 03 Alexandria, VA

NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 403 Washington DC; Code 405 Wash, DC; Code 407 (D Scheesele) Washington, DC; Code FPO-1C Washington DC; Contracts, ROICC, Annapolis MD; FPO-1 Washington, DC; FPO-1EA5 Washington DC; Library, Washington, D.C.

NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA

NAVFACENGCOM - NORTH DIV. CO; Code 04 Philadelphia, PA; Code 09P Philadelphia PA; Code 1028, RDT&ELO, Philadelphia PA; Code 111 Philadelphia, PA; Code 4012 AB (A. Bianchi) Philadelphia, PA; Library, Philadelphia, PA; ROICC, Contracts, Crane IN

NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 2011 Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI

NAVFACENGCOM - SOUTH DIV. Code 403, Gaddy, Charleston, SC; Code 408 Charleston, SC; Code 411 Soil Mech & Paving BR Charleston, SC; Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC

NAVFACENGCOM - WEST DIV 102, AROICC, Contracts, Twentynine Palms CA, Code 04B San Bruno, CA, Library, San Bruno, CA; 09P/20 San Bruno, CA, RDT&ELO Code 2011 San Bruno, CA

NAVFACENGCOM CONTRACTS ROICC MCAS El Toro; AROICC, NAVSTA Brooklyn, NY, ROICC, Point Mugu, CA; AROICC, Quantico, VA; Colts Neck, NJ, Contracts, AROICC, Lemoore CA, Dir, Eng Div., Exmouth, Australia, Eng Div dir, Southwest Pac, Manila, PI, NAS, Jacksonville, FL, OICC, Southwest Pac, Manila, PI, OICC-ROICC, NAS Oceana, Virginia Beach, VA, OICC ROICC, Balboa Panama Canal, OICC ROICC, Norfolk, VA, ROICC AF Guam, ROICC Code 495 Portsmouth VA, ROICC Key West FL; ROICC Rota Spain; ROICC, Diego Garcia Island; ROICC, Keflavik, Iceland, ROICC, NAS Corpus Christi, TX, ROICC, Pacific, San Bruno CA, ROICC, Yap; ROICC-OICC-SPA, Norfolk, VA

NAVHOSP PWD - Engr Div, Beaufort, SC

NAVMAG PWD - Engr Div, Guam; SCE, Guam; SCE, Subic Bay, R.P

NAVOCEANO Code 3432 (J. DePalma), Bay St. Louis MS; Library Bay St. Louis, MS

NAVOCEANSYSCEN Code 4473 Bayside Library, San Diego, CA, Code 4473B (Tech Lib) San Diego, CA, Code 5221 (R Jones) San Diego Ca, Code 523 (Hurley), San Diego, CA, Code 6700, San Diego, CA, Code 811 San Diego, CA

NAVORDMISTESTFAC PWD - Engr Dir, White Sands, NM

NAVORDSTA PWD - Dir, Engr Div, Indian Head, MD, PWO, Louisville KY

NAVPETOFF Code 30, Alexandria VA

NAVPETRES Director, Washington DC

NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S31, Norfolk VA, Harbor Clearance Unit Two, Little Creek, VA; SCE *Coronado*, SD,CA

NAVRADRECFAC PWO, Kami Seya Japan

NAVREGMEDCEN Code 3041, Memphis, *Millington* TN, PWD - Engr Div, Camp Lejeune, NC; PWO Portsmouth, VA, PWO, Camp Lejeune, NC

NAVREGMEDCEN PWO, Okinawa, Japan

NAVREGMEDCEN SCE; SCE San Diego, CA, SCE, Camp Pendleton CA, SCE, Guam; SCE, Newport, RI, SCE, Oakland CA

NAVREGMEDCEN SCE, Yokosuka, Japan

NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA

NAVSCSOL PWO, Athens GA

NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code 05E1, Wash, DC; Code PMS 395 A 3, Washington, DC; SEA 04E (L Kess) Washington, DC; SEA05E1, Washington, D.C.

NAVSECGRUACT Facil. Off., Galeta Is. Panama Canal; PWO, Adak AK; PWO, Edzell Scotland, PWO, Puerto Rico; PWO, Torri Sta, Okinawa

NAVSECSTA PWD - Engr Div, Wash., DC

NAVSHIPREPFAC SCE Subic Bay

NAVSHIPYD Bremerton, WA (*Carr Inlet* Acoustic Range), Code 134, Pearl Harbor, HI; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA, Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 440 *Portsmouth* NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA, Code 453 (Util. Supr), Vallejo CA, Commander, Philadelphia, PA; L.D. Vivian; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA, PWD (Code 450-HD) Portsmouth, VA, PWD (Code 453-HD) SHPO 03, Portsmouth, VA; PWD (Code 457-HD) Shop 07, Portsmouth, VA; PWD (Code 460) Portsmouth, VA; PWO, Bremerton, WA, PWO, Mare Is., PWO, Puget Sound, SCE, Pearl Harbor HI; *Tech Library*, Vallejo, CA

NAVSTA Adak, AK; CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY, Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL, *Dir Mech Engr* 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba, Maint. Div Dir/Code 531, Rodman Panama Canal; PWD (LTJG P.M. Motolenich), Puerto Rico, PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Guantanamo Bay Cuba; PWO, Keflavik Iceland, PWO, Mayport FL, SCE, Guam; SCE, Pearl Harbor HI; SCE, San Diego CA; SCE, Subic Bay, R.P., Utilities Engr *Off. Rota Spain*

NAVSUBASE Code 23 (Slowey) Bremerton, WA

NAVSUPPACT CO, Naples, Italy; PWO Naples *Italy*

NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD

NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD

NAVTECHTRACEN SCE, Pensacola FL

NAVTELCOMMCOM Code 53, Washington, DC

NAVWPNCEN Code 2636 China Lake, Code 3803 China Lake, CA, PWO (Code 266) China Lake, CA, ROICC (Code 702), China Lake CA

NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ, Code 092, Concord CA, Code 092A, Seal Beach, CA; Maint. Control Dir., Yorktown VA

NAVWPNSTA PW Office Yorktown, VA

NAVWPNSTA PWD - Maint. Control Div., Concord, CA, PWD - Supr Gen Engr, Seal Beach, CA, PWO, Charleston, SC; PWO, Seal Beach CA

NAVWPNSUPPCEN Code 09 Crane IN

NCBU 405 OIC, San Diego, CA

NCTC Const. Elec. School, Port Hueneme, CA
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 400, Gulfport MS; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS
NCBU 411 OIC, Norfolk VA
NCR 20, Code R70; 20, Commander
NMCB 74, CO; FIVE, Operations Dept; Forty, CO; THREE, Operations Off.
NOAA (Dr. T. Mc Guinness) Rockville, MD; Library Rockville, MD
NORDA Code 440 (Ocean Rsch Off) Bay St. Louis MS
NRL Code 5800 Washington, DC; Code 8441 (R.A. Skop), Washington DC
NROTC J.W. Stephenson, UC, Berkeley, CA
NSC Code 54.1 Norfolk, VA
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NTC OICC, CBU-401, Great Lakes IL
NUSC Code 131 New London, CT; Code 5202 (S. Schady) New London, CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI; Code TA131 (G. De la Cruz), New London CT
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Central Regional Office, Boston, MA; Code 221, Arlington VA; Code 485 (Silva) Arlington, VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA; 1, CSWC D Wellington, San Diego, CA
PMTC Pat. Counsel, Point Mugu CA
PWC ACE Office Norfolk, VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Library, Code 120C, San Diego, CA; Code 128, Guam; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 200, Guam; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; Library, Pensacola, FL; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Subic Bay, R.P.; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam; **Library, Yokosuka, JA**
SPCC PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA
TVA Smelser, Knoxville, Tenn.; Solar Group, Arnold, Knoxville, TN
UCT ONE OIC, Norfolk, VA
UCT TWO OIC, Port Hueneme CA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USAF REGIONAL HOSPITAL Fairchild AFB, WA
USAF SCHOOL OF AEROSPACE MEDICINE Hyperbaric Medicine Div, Brooks AFB, TX
USCG (Smith), Washington, DC; G-EOE-4 (T Dowd), Washington, DC; G-MMT-4/82 (J Spencer)
USDA Forest Products Lab. Madison WI; Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, Bowers, Atlanta, GA
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; Mech. Engr. Dept. (C. Wu), Annapolis MD; USNA Sys Eng Dept, Annapolis, MD; PWO Annapolis MD
USS FULTON WPNS Rep. Offr (W-3) New York, NY
WATER & POWER RESOURCES SERVICE (Smoak) Denver, CO
AMERICAN CONCRETE INSTITUTE Detroit MI (Library)
ARIZONA Kroelinger Tempe, AZ; State Energy Programs Off., Phoenix AZ
AUBURN UNIV. Bldg Sci Dept, Lechner, Auburn, AL
BERKELEY PW Engr Div, Harrison, Berkeley, CA
BONNEVILLE POWER ADMIN Portland OR (Energy Consrv. Off., D. Davey)
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CALIF. DEPT OF NAVIGATION & OCEAN DEV. Sacramento, CA (G. Armstrong)
CALIF. MARITIME ACADEMY Vallejo, CA (Library)
CALIFORNIA STATE UNIVERSITY LONG BEACH, CA (CHELAPATI)
CLARKSON COLL OF TECH G. Batson, Potsdam NY
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DRURY COLLEGE Physics Dept, Springfield, MO
DUKE UNIV MEDICAL CENTER B. Muga, Durham NC
UNIVERSITY OF DELAWARE (Dr. S. Dexter) Lewes, DE
FLORIDA ATLANTIC UNIVERSITY Boca Raton FL (W. Hartt); Boca Raton, FL (McAllister)
FOREST INST. FOR OCEAN & MOUNTAIN Carson City NV (Studies - Library)

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HARVARD UNIV Dept. of Architecture, Dr. Kim, Cambridge, MA
HAWAII STATE DEPT OF PLAN & ECON DEV Honolulu HI (Tech Info Ctr)
INSTITUTE OF MARINE SCIENCES Morehead City NC (Director)
IOWA STATE UNIVERSITY Dept. Arch. McKrown, Ames, IA
WOODS HOLE OCEANOGRAPHIC INST Woods Hole MA (Winget)
KEENE STATE COLLEGE Keene NH (Cunningham)
LEHIGH UNIVERSITY BETHLEHEM, PA (MARINE GEOTECHNICAL LAB., RICHARDS); Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Div Of R&D, Baton Rouge, LA
MAINE MARITIME ACADEMY CASTINE, ME (LIBRARY)
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MICHIGAN TECHNOLOGICAL UNIVERSITY Houghton, MI (Haas)
MISSOURI ENERGY AGENCY Jefferson City MO
MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge, MA (Harleman)
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATURAL ENERGY LAB Library, Honolulu, HI
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NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
NYS ENERGY OFFICE Library, Albany NY
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PENNSYLVANIA STATE UNIVERSITY STATE COLLEGE, PA (SNYDER)
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SAN DIEGO STATE UNIV. I. Noorany San Diego, CA
SCRIPPS INSTITUTE OF OCEANOGRAPHY LA JOLLA, CA (ADAMS); San Diego, CA (Marina Phy. Lab Spiess)
SEATTLE U Prof Schwaegler Seattle WA
SRI INTL Phillips, Chem Engr Lab, Menlo Park, CA
STATE UNIV. OF NEW YORK Buffalo, NY; Fort Schuyler, NY (Longobardi)
STATE UNIV. OF NY AT BUFFALO School of Medicine, Buffalo, NY
TEXAS A&M UNIVERSITY College Station TX (CE Dept. Herbich); W.B. Ledbetter College Station, TX
UNIVERSITY OF CALIFORNIA BERKELEY, CA (CE DEPT, GERWICK); Berkeley CA (E. Pearson); DAVIS, CA (CE DEPT, TAYLOR); Energy Engineer, Davis CA; LIVERMORE, CA (LAWRENCE LIVERMORE LAB, TOKARZ); UCSF, Physical Plant, San Francisco, CA
UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
UNIVERSITY OF FLORIDA Dept Arch., Morgan, Gainesville, FL
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WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan), Library, Pittsburgh PA
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WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)
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DOBROWOLSKI, J.A. Altadena, CA
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FISHER San Diego, Ca
GERWICK, BEN C. JR San Francisco, CA
KETRON, BOB Ft Worth, TX
KRUZIC, T.P. Silver Spring, MD
LAFKIN Seattle, WA
LAYTON Redmond, WA
PAULI Silver Spring, MD
R.F. BESIER Old Saybrook CT
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